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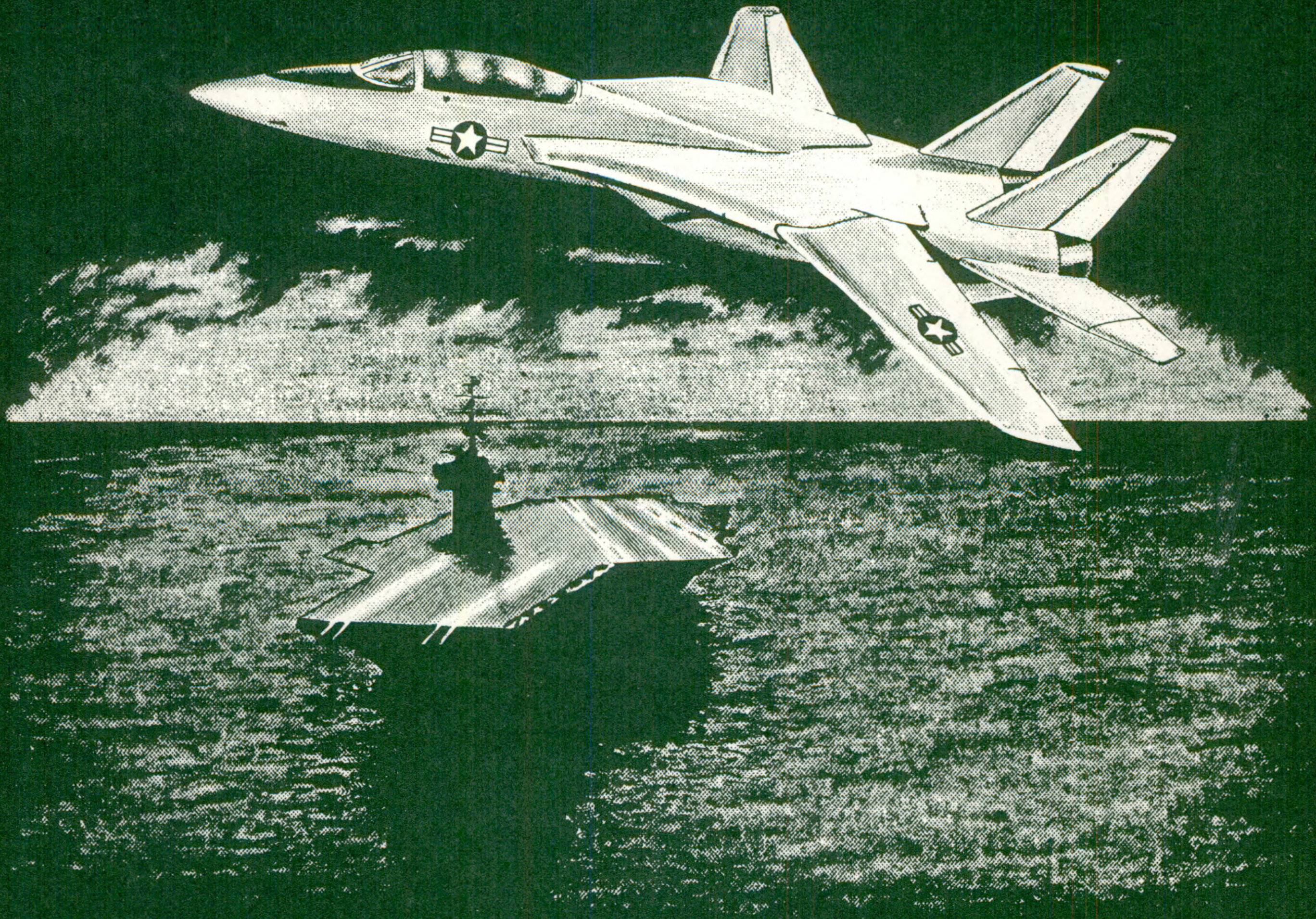

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AVIATION

FIRE CONTROL TECHNICIAN 3 & 2

BUREAU OF NAVAL PERSONNEL

RATE TRAINING MANUAL NAVPERS 10387-A

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PREFACE

This Rate Training Manual is one of a series of training manuals prepared especially for enlisted personnel of the U.S. Navy and Naval Reserve who are preparing for advancement to AQ3 and AQ2.

The Manual of Qualifications for Advancement, NavPers 18068-B (Revised), has been used as a guide in the selection of the content for this training manual. However, this manual does not duplicate material contained in Basic Electricity, NavPers 10086-B, and Basic Electronics, NavPers 10087-B. Trainees should become familiar with the Qualifications for Advancement to insure that required material contained in these basic manuals is also studied.

This training manual has been prepared by the Navy Training Publications Center, Millington, Tennessee, for the Bureau of Naval Personnel. Credit is given to the Naval Air Technical Training Center, located at Millington, Tennessee, the Naval Examining Center, Great Lakes, Illinois, the Naval Aviation Integrated Support Center, Patuxent River, Maryland, and to the Naval Air Systems Command, for technical reviews.

1971 Edition

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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READING LIST

For trainees that have not had high school algebra and trigonometry.

E 164 Beginning Algebra I
E 165 Beginning Algebra II

or

PA 164-165 Beginning Algebra I - II
(Programed)

For trainees that have had high school algebra and trigonometry.

D 166 Advanced Algebra
D 188 Trigonometry
E 290 Physics I
E 291 Physics II
C 781 Fundamentals of Electricity
B 788 Introduction to Electronics I
B 789 Introduction to Electronics II

"Members of the United States Armed Forces Reserve Components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more."

CHAPTER 1

AVIATION FIRE CONTROL TECHNICIAN 3 & 2

This training manual is designed as a self-study text for use by those personnel of the Navy and Naval Reserve who are preparing to meet the professional (technical) qualifications for advancement to Petty Officer Third Class and Petty Officer Second Class in the rating of Aviation Fire Control Technician. Minimum professional qualifications for advancement in all ratings are listed in the Manual of Qualifications for Advancement, NavPers 18068 (Series). The qualification list which was used as a guide in the preparation of this manual was current in the 1971 revision of that manual. Therefore, changes in the qualifications occurring after the 1971 revision may not be reflected in the information presented here.

This manual does not contain coverage on all "quals" listed in the "Quals" Manual. Some of the "quals" listed are wholly or partially covered by the following basic Rate Training Manuals:

Blueprint Reading and Sketching, NavPers 10077-C, Chapters 4, 5, and 6.

Basic Handtools, NavPers 10085-A, Part 1, Sec. 2 and 3; Part 2, Sec. 7.

Basic Electricity, NavPers 10086-B.

Basic Electronics, NavPers 10087-B, Chapters 1-11, 15, 16, and 17.

Basic Machines, NavPers 10624-A.

Fluid Power, NavPers 16193-A.

Digital Computer Basics, NavPers 10088.

It is important that those personnel studying for advancement be familiar with the content of the above listed chapters; advancement examinations will also be based on this material.

The contents of this training manual involve almost all the technical subject matter with which the Aviation Fire Control Technician must become proficient. Other areas covered include safety.

ENLISTED RATING STRUCTURE

The present enlisted rating structure consists of general ratings and service ratings.

General ratings identify broad occupational fields of related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

Service ratings identify subdivisions or specialties within a general rating. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

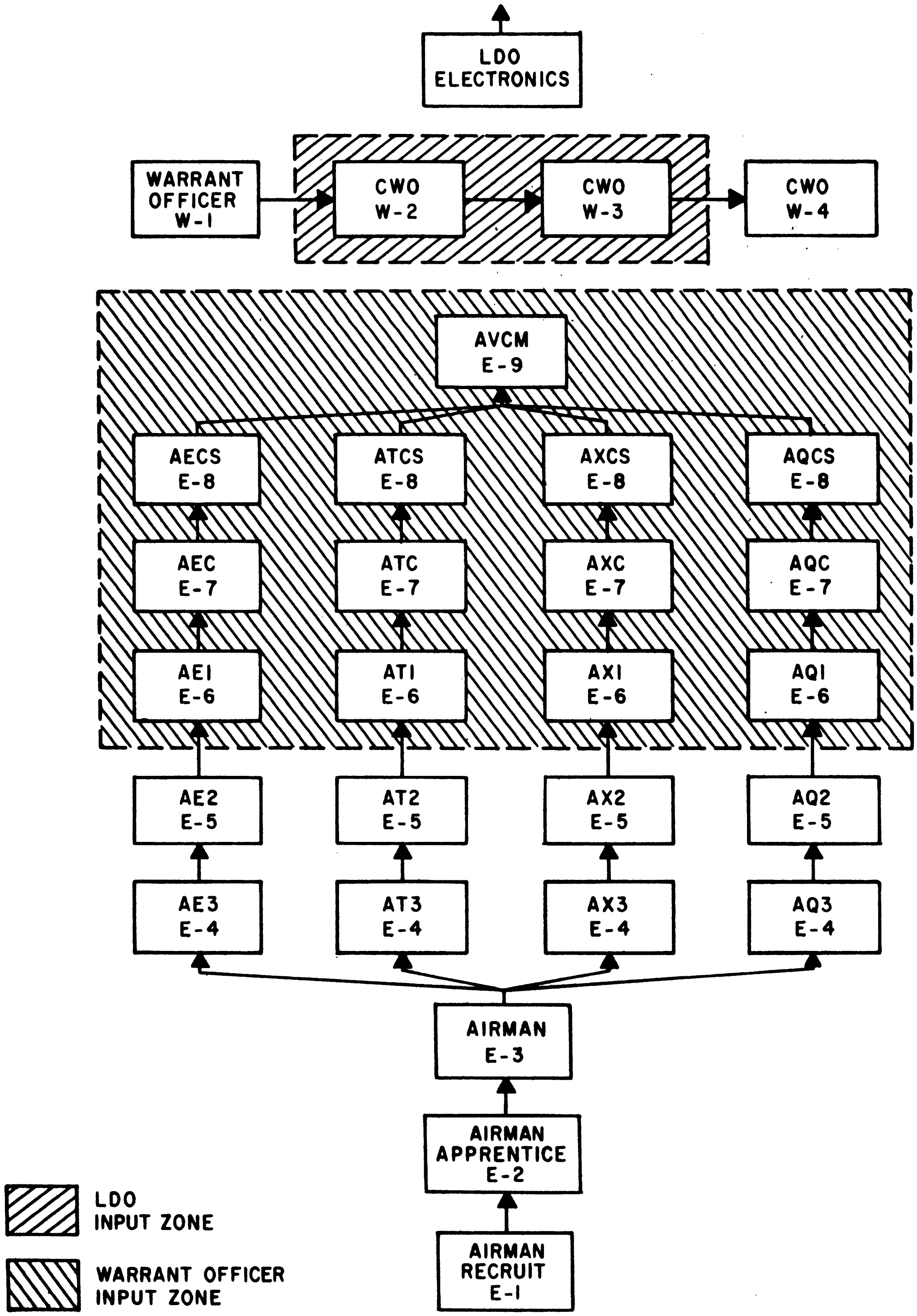
AVIATION FIRE CONTROL TECHNICIAN RATING

The Aviation Fire Control Technician rating is a general rating up to E-9. At pay grade E-9 the Aviation Fire Control Technician rating loses its identity; personnel of pay grade E-8 in this rating, along with AECS, AXCS, and ATCS, advance to Master Chief Avionics Technician, AVCM. Figure 1-1 illustrates all paths of advancement for an Airman Recruit to Master Chief Avionics Technician (AVCM), Chief Warrant Officer (W-4), or to Limited Duty Officer (LDO). The advancement paths through the AQ rating is emphasized in the figure. Shaded areas indicate career stages where qualified enlisted men may advance to Warrant Officer (W-1), and selected Warrant Officers may advance to Limited Duty Officer. Personnel in enlisted rates and warrant ranks may advance only as indicated by the lines.

Aviation Fire Control Technicians inspect and perform organizational and intermediate maintenance on aircraft weapons systems, including weapons control radar, computers, computing sights, gyroscopes, accessories, and related equipment; and air-launched guided missile equipment.

As an Aviation Fire Control Technician Third Class or Second Class, your assignment possibilities cover a wide range of duties and responsibilities. Your specific duties will depend to a great extent upon the type of organization to which you are attached.

You most likely will be assigned to billets concerning the maintenance of aircraft weapons systems and associated equipment. As an AQ,



AE.1

Figure 1-1.—Paths of advancement.

you may be attached to any one of the several types of aircraft maintenance activities.

In the aircraft squadron, your duties are concerned primarily with the avionics division of the maintenance department. You work under the supervision of the avionics division chief on all routine maintenance and minor repair, and perform such other duties as may be assigned by the avionics officer. In some squadrons you may serve as plane captain.

In the maintenance department of a naval air station or on an aircraft carrier, you may be assigned to an AIMD where you will perform intermediate maintenance on aircraft weapons systems components.

One of the shore duty billets available to you as an AQ2 may be assignment to the Naval Air Technical Training Center, Millington, Tennessee, as an instructor in the Avionics Technician School (Class A) or Advanced First Term Avionics Course (Class B).

In addition to the above listed instructor billets, the AQ may be assigned to instructor duty with a Naval Air Maintenance Training Detachment (NAMTD). NAMTD's are located at shore stations on both coasts. Personnel assigned to this duty are first sent to Naval Air Maintenance Training Group headquarters at Millington, Tennessee, for a period of indoctrination and instruction.

Instructor billets are normally filled on a voluntary basis. Detailed information concerning assignment to instructor duty is contained in the Enlisted Transfer Manual, NavPers 15909 (Series).

Since you have been in pay grade E-3 or E-4 for some time, you realize that more leadership is required of the higher rates. Not only are you required to have superior knowledge, but you are also required to have the ability to handle personnel. This ability increases in importance as you advance through the various rates as a petty officer.

In General Order No. 21, the Secretary of the Navy outlined some of the most important aspects of naval leadership. Naval leadership means the art of accomplishing the Navy's mission through people. It is the sum of those qualities of intellect, of human understanding, and of moral character that enable a man to inspire and to manage a group of people successfully. Effective leadership, therefore, is based on personal example, good management practices, and moral responsibility. The term leadership includes all three of these elements.

The current Navy Leadership Program is designed to keep the spirit of General Order No. 21 ever before you. If the threefold objective is carried out effectively in every command, the program will make of you a better leader of men in your present billet and in your future assignments. As you advance up the leadership ladder, more and more your worth to the Navy will be judged on the basis of the amount of efficient work you obtain from your subordinates rather than how much of the actual work you do yourself.

For information on the practical application of leadership and supervision, study Military Requirements for Petty Officer 3 & 2, NavPers 10056-C.

ADVANCEMENT

Some of the rewards of advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

The advantages of advancement are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By advancement, you increase your value to the Navy in two ways: First, you become more valuable as a technical specialist in your own rating; and second, you become more valuable as a person who can train others, and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.
2. Complete the required Rate Training Manuals by either demonstrating a knowledge of the material in the manual by passing a locally prepared and administered test, or by passing the Enlisted Correspondence Course based on the Rate Training Manual.
3. Demonstrate your ability to perform all the practical requirements for advancement by completing the Record of Practical Factors, NavPers 1414/1.

4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.

5. Successfully complete the applicable military/leadership examination which is required prior to participating in the advancement (professional) examination.

Some of these general requirements may be modified in certain ways. Figure 1-2 gives a more detailed view of the requirements for advancement of active duty personnel; figure 1-3 gives this information for inactive duty personnel.

Remember that the requirements for advancement can change. Check with your educational services office to be sure that you know the most recent requirements.

Advancement is not automatic. After you have met all the requirements, you are eligible for advancement. You will actually be advanced only if you meet all the requirements (including making a high enough score on the written examination) and if quotas permit.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement? You must study the qualifications for advancement, work on the practical factors, study the required Rate Training Manuals, and study other material that is required. You will need to be familiar with the following:

1. Manual of Qualifications for Advancement, NavPers 18068 (Series).
2. Record of Practical Factors, NavPers 1414/1.
3. Training Publications for advancement, NavPers 10052 (Series).
4. Applicable Rate Training Manuals and their companion Enlisted Correspondence Courses.
5. Examinations for advancement.

Collectively, these documents make up an integrated training package tied together by the qualifications. The following paragraphs describe these materials and give some information on how each one is related to the others.

"Quals" Manual

The Manual of Qualifications for Advancement, NavPers 18068 (Series), gives the minimum requirements for advancement. This manual is usually called the "Quals" Manual, and the qualifications themselves are often called "quals." The qualifications are of two general types: military requirements, and professional (or technical) qualifications.

Military requirements apply to all ratings rather than to any one particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all other ratings.

Professional qualifications are technical or professional requirements that are directly related to the work of each rating.

Both the military requirements and the professional qualifications are divided into subject matter groups; then, within each subject matter group, they are divided into practical factors and knowledge factors. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rate.

The qualifications for advancement and a bibliography of study materials are available in your educational services office. Study these qualifications and the military requirements carefully. The written examination for advancement will contain questions relating to the knowledge factors and the knowledge aspects of the practical factors of both the military requirements and the professional qualifications. If you are working for advancement to second class, remember that you may be examined on third class qualifications as well as on second class qualifications.

It is essential that the "quals" reflect current requirements of fleet and shore operations, and that new fleetwide technical, operational, and procedural developments be included. For these reasons, the qualifications are continually under evaluation. Although there is an established schedule for revisions to the "quals" for each rating, urgent changes to the "quals" may be made at any time. These revisions are issued in the form of changes to the "Quals" Manual. Therefore, never trust any set of "quals" until you have checked the change number against an up-to-date copy of the "Quals" Manual. Be sure you have the latest revision.

Record of Practical Factors

Before you can take the Navy-wide examination for advancement, there must be an entry in

REQUIREMENTS*	E1 to E2	E2 to E3	#† E3 to E4	#E4 to E5	† E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of	6 mos. as E-2.	6 mos. as E-3	12 mos. as E-4	24 mos. as E-5.	36 mos. as E-6. 8 years total enlisted service.	36 mos as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3, PN 3, FTB 3, MT 3,			Class B for AGC MUC, MNC.††		
PRACTICAL FACTORS	Locally prepared check-offs.	Record of Practical Factors, NavPers 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS**	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.				Navy-wide, selection board.	
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* All advancements require commanding officer's recommendation.

† 1 year obligated service required for E-5 and E-6; 2 years for E-7, E-8 and E-9.

# Military leadership exam required for E-4 and E-5.

** For E-2 to E-3, NAVEXAMCEN exams or locally prepared tests may be used.

†† Waived for qualified EOD personnel.

Figure 1-2.—Active duty advancement requirements.

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	6 mos.	6 mos.	12 mos.	24 mos.	36 mos. with total 8 yrs service	36 mos. with total 11 yrs service	24 mos. with total 13 yrs service
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS	▨		Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavPers 1414/1, must be completed for all advancements.							
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam		Standard Exam required for all PO Advancements. Also pass Military Leadership Exam for E-4 and E-5.				Standard Exam, Selection Board.	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* Recommendation by commanding officer required for all advancements.
† Active duty periods may be substituted for training duty.

Figure 1-3.—Inactive duty advancement requirements.

your service record to show that you have qualified in the practical factors of both the military requirements and the professional qualifications. A special form known as the Record of Practical Factors, NavPers 1414/1 (plus the abbreviation of the appropriate rating), is used to keep a record of your practical factor qualifications. The form lists all practical factors, both military and professional. As you demonstrate your ability to perform each practical factor, appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically to the Manual of Qualifications for Advancement and revised forms of NavPers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes. The Record of Practical factors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rate but which are not identified as minimum qualifications for advancement.

If you are transferred before you qualify in all practical factors, NavPers 1414/1 should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form is actually inserted in your service record before you are transferred. If the form is not in your service record, you will be required to start all over again and requalify in the practical factors which have already been checked off.

A second copy of the Record of Practical Factors should be made available to each man in pay grades E-2 through E-8 for his personal record and guidance.

The importance of NavPers 1414/1 cannot be overemphasized. It serves as a record to indicate to the petty officers and officers supervising your work that you have demonstrated proficiency in the performance of the indicated practical factors and is part of the criteria utilized by your commanding officer when he considers recommending you for advancement. In addition, the proficient demonstration of the applicable practical factors listed on this form can aid you in preparing for the examination for advancement. Remember that the knowledge aspects of the practical factors are covered in the examinations for advancement. Certain knowledge is required to demonstrate these practical factors and additional knowledge can be acquired during the demonstration. Knowledge factors pertain to that knowledge which is required to perform a certain job. In other words, the knowledge factors required for a certain rating depend upon the jobs (practical factors) that must be performed by personnel of that rating. Therefore, the knowledge required to proficiently demonstrate these practical factors will definitely aid you in preparing for the examination for advancement.

NavPers 10052

Training Publications for Advancement, NavPers 10052 (Series), is a very important publication for anyone preparing for advancement. This bibliography lists required and recommended Rate Training Manuals and other reference material to be used by personnel working for advancement. NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the NavPers number. When using this publication, be sure that you have the most recent edition.

If extensive changes in qualifications occur between the annual revisions of NavPers 10052, a supplementary list of study material may be issued in the form of a BuPers Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications. If changes have been made, see if a BuPers Notice has been issued to supplement NavPers 10052.

The required and recommended references are listed by rate level in NavPers 10052. If you are working for advancement to third class, study the material that is listed for third class. If you are working for advancement to second class, study the material that is listed for second class. Remember that you are also responsible for the references listed at the third class level.

In using NavPers 10052, you will notice that some Rate Training Manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY—that is, it must be completed at the indicated rate level before you are eligible to take the Navy-wide examination for advancement. Each mandatory manual may be completed by passing the appropriate enlisted correspondence course that is based on the mandatory training manual; passing locally prepared tests based on the information given in the training manual, or in some cases, successfully completing an appropriate Class A School.

Do not overlook the section of NavPers 10052 which lists the required and recommended references relating to the military standards/requirements for advancement. For example, all personnel must complete the Rate Training Manual, Requirements for Petty Officer 3 & 2, NavPers 10056 (Series), for the appropriate rate level before they can be eligible to advance.

The references in NavPers 10052 which are recommended, but not mandatory, should also be studied carefully. All references listed in NavPers 10052 may be used as source material for the written examinations at the appropriate rate levels.

Rate Training Manuals

There are two general types of Rate Training Manuals. Rating manuals (such as this one) are prepared for most enlisted rates, giving information that is directly related to the professional qualifications. Basic manuals give information that applies to more than one rate and rating. Basic Electricity, NavPers 10086 (Series), is an example of a basic manual, because many ratings use it for reference.

Rate Training Manuals are revised from time to time to keep them up to date technically. The revision of a Rate Training Manual is identified by a letter following the NavPers number. You can tell whether any particular copy of a Rate Training Manual is the latest edition by checking the NavPers number and the letter following this number in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061 (Series). (NavPers 10061 is actually a catalog that lists current training manuals and correspondence courses; you will find this catalog useful in planning your study program.)

Rate Training Manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this manual and other Navy training publications when you are preparing for advancement.

1. Study the military requirements and the professional qualifications for your rate before you study the training manual, and refer to the "quals" frequently as you study. Remember, you are studying the training manual in order to meet these "quals."
2. Set up a regular study plan. If possible, schedule your studying for a time of day when you will not have too many interruptions or distractions.
3. Before you begin to study any part of the training manual intensively, become familiar with the entire manual. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the manual without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.
4. Look at the training manual in more detail, to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a clear picture of the scope and content of the manual. As you look through the manual in this way, ask yourself some questions: What do I need to learn about this? What do I already know about this? How is this information related to information given in other chapters? How is this information related to the qualifications for advancement?
5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit—it may be a chapter, a section of a chapter, or a subsection. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.
6. In studying any one unit—chapter, section, or subsection—write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.
7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.
8. When you have finished studying a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without referring to the training manual, write down the main ideas that you have learned from studying this unit. Do not quote the manual. If you cannot give these ideas in your own words, the chances are that you have not really mastered the information.
9. Use Enlisted Correspondence Courses whenever you can. The correspondence courses are based on Rate Training Manuals or on other appropriate texts. As mentioned before,

completion of a mandatory Rate Training Manual can be accomplished by passing an Enlisted Correspondence Course based on the Rate Training Manual. You will probably find it helpful to take other correspondence courses, as well as those based on mandatory training manuals. Taking a correspondence course helps you to master the information given in the training manual, and also helps you see how much you have learned.

10. Think of your future as you study Rate Training Manuals. You are working for advancement to third class or second class right now, but someday you will be working toward higher rates. Anything extra that you can learn now will help you.

SOURCES OF INFORMATION

One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the professional qualifications of your rating.

Some of the publications described in this manual are subject to change or revision from time to time—some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you perform efficiently or to advance; it is likely to be a waste of time, and may even be seriously misleading.

CHAPTER 2

SAFETY

In the performance of his normal duties, the naval avionics technician is exposed to many potentially dangerous conditions and situations. No Rate Training Manual, no set of rules or regulations, no listing of hazards can make working conditions completely safe. However, it is possible for the technician to complete a full naval career without serious accident or injury. Attainment of this goal requires that he be aware of the main sources of danger, and that he remain constantly alert to those dangers. He must take the proper precautions and practice the basic rules of safety. He must be safety conscious at all times, and this safety consciousness must become second nature to him.

Much pertinent safety information is contained in Rate Training Manuals. Of particular worth among these manuals are Airman, NavPers 10307-C, and Standard First Aid Training Course, NavPers 10081-B. In addition, directives concerning safety are published by all major commands on those specific hazards and procedures falling under the cognizance of those commands. The Chief of Naval Operations has recently issued a listing of specific safety precautions compiled by the Navy Department. This publication cross references safety directives by subject matter and by the identifying designation.

The purpose of this chapter is to indicate some of the major hazards encountered in the normal working conditions of the technician, and to indicate some of the basic precautions that must be observed. Although many of these hazards and precautions are general and apply to all personnel, some of them are peculiar or especially applicable to avionics maintenance personnel.

GENERAL SAFETY

Most accidents which occur in noncombat operations can be prevented if the full cooperation of personnel is gained, and if care is exercised to eliminate unsafe acts and conditions. In the following paragraphs, some general safety rules are listed. These rules apply to personnel in all types of activities, and each individual should strictly observe the following precautions as applicable to his work or duty:

1. Report any unsafe condition or any equipment or material which he considers to be unsafe.
2. Warn others whom he believes to be endangered by known hazards or by failure to observe safety precautions.
3. Wear or use available protective clothing or equipment or the type approved for safe performance of his work or duty.
4. Report any injury or evidence of impaired health occurring in the course of work or duty.
5. Exercise, in the event of any unforeseen hazardous occurrence, such reasonable caution as is appropriate to the situation.

Safety precautions in this chapter are not intended to replace information given in instructions or maintenance manuals. If at any time there is doubt as to what steps and procedures to follow, consult the leading petty officer.

AVIATION SAFETY

For purposes of this discussion, the term AVIATION SAFETY is used in connection with all functions and operations having to do with aircraft and with materials and equipment used in connection with aircraft, hangars, parking areas and ramps, and flight lines and taxiways.

Hazards

Among the major hazards present in aviation activities are the following:

1. Fire or explosion caused by the application of external or internal power to an aircraft which is in some state of malfunction or disrepair, or undergoing maintenance or modification; or which create explosive vapors; or which have electrical short circuits.
2. Personal injuries sustained in falling from aircraft or workstands, being burned or blown about by jet blast or prop wash, being struck by objects blown about by jet blast or

prop wash, being sucked into jet intakes, or being struck by propeller or rotor blades.

3. Being run down or over, due to lack of alertness to the movement of taxiing aircraft or ground equipment vehicles.

4. Explosion of aircraft batteries due to improper charging methods or to current overloading on ground tests within an aircraft.

5. Injuries (especially common during the hours of darkness) caused by encounter with tiedown lines, padeyes, chocks, protruding parts of aircraft or other equipment, or other such items about a deck or ramp.

6. Canopy, ejection seat, ordnance, and other "wrong switch at the wrong time" type accidents.

7. Misuse of, and abuse to, flight safety equipment, parachutes, "Mae Wests," liferafts, etc.

8. Accidents caused by careless workmanship, such as leaving tools or other extraneous materials in aircraft bilges, engine nacelles, intake or exhaust ducts, or movable parts of aircraft structures.

Precautions

Many safety precautions are of general nature and apply to all types of aircraft; however, others vary in specific details between specific models. It is imperative that all personnel whose duties take them into the vicinity of aircraft be familiar with both general safety precautions and with the specific precautions for the model with which they are associated. The following partial list of safety precautions is not intended to represent a complete listing. It is intended to serve merely as a guide to illustrate the general types of safety items which must be included in the safety education and training programs of all aviation activities.

1. Appropriate warning signs must be placed in or around aircraft or work areas whenever and wherever an unsafe condition is known or thought to exist. Strict attention and adherence to the signs must be enforced.

2. Smoking regulations and prohibitions must be observed and strictly enforced. Since explosive vapors may be ignited from any source of open flame or from electrical arcing, these conditions are subject to the same restrictions as smoking.

3. Radio and radar transmitters should not be trained on potentially explosive areas or on personnel, nor should they be operated in close proximity to flammable or explosive materials or vapors. This hazard is discussed in considerable detail in a later portion of this chapter.

4. Storage batteries or electric cables should not be disconnected or removed from their circuits in any enclosed space immediately following flight or fueling operations without first ventilating the space to remove accumulated vapors. All switches should be opened and all electric power disabled prior to disconnecting batteries or electric cables.

5. Combustible materials such as rags and clean waste should be stowed in covered metal containers. Used waste and rags should never be discarded near aircraft; they should be put into plainly marked metal containers.

6. Aircraft should be parked with parking brakes set, chocks in place, and tiedowns installed. If manila rope is used for tiedowns, some slack must be allowed; manila rope will shrink when wet, and may result in undue strain on the aircraft.

7. During jet engine runup, foreign objects may be drawn into the intake ducts, causing damage to the engine compressor section and the danger of flying debris from the exhaust section. During maintenance procedures involving engine operation, a careful inspection of the intake ducts and surrounding areas must be performed to insure the absence of foreign objects; and engine air intake safety screens must be properly installed. Parking areas, turnup areas, taxiways, and runways must be kept clean and free of stones, hardware, and other foreign objects.

MACHINERY

When working with, on, or around machinery, be constantly alert to moving parts. Never reach into the path of moving parts of a machine, either with the hands or with any other item. Always follow prescribed procedures in making adjustments on machinery while in operation; if at all possible, make the adjustments with the machinery shut down. Never wear loose, baggy, or ill-fitting clothing in the immediate vicinity of machinery. Remove rags, papers, etc., from pockets; remove ties, wristwatches, rings, etc.; button shirt sleeves; make sure dogtags are inside the undershirt or removed completely.

ELECTRICAL EQUIPMENT

The safety precautions and considerations listed above for machinery apply also to electrical equipment. In addition to the danger of being grabbed or struck by moving parts, electrical equipments also present the dangers of fire, explosion, electrical shock, and burns.

Electrical equipment should never be operated in areas where explosive vapors are present or suspected, unless the equipment is of the special explosionproof design made expressly for use in such areas.

When working with, on, or around electrical equipment, avoid contact with power circuits. If it is necessary to work on energized circuits or on electrical equipment while in operation, use adequate protective materials (rubber gloves, insulated tools, insulating matting, etc.) and extreme care. Never work on electrical equipment when standing in water, when perspiring heavily, or when in contact with metal decks or other metallic structures or equipment. When preparing to work on deenergized electrical circuits, make sure the power switch is off, and then use a grounding probe to eliminate any residual charge that may exist in the circuit.

These precautions apply to low voltage equipments as well as to high voltage equipments. It must be remembered, in connection with electrical shock and burns, that it is the current that does the damage, not the voltage.

VOLATILE FLUIDS

Volatile fluids are liquids which evaporate rapidly at relatively low temperatures. In this discussion, the term will be used to include pressurized gases escaping from their containers. In safety considerations, two main types of fluids must be considered: First, those which result in explosive vapors; and second, those which are toxic.

Explosive Vapors

Aviation fuels, alcohol, painting materials and supplies, insulating varnish, certain cleaning supplies, and many industrial gases produce potentially explosive vapors when allowed to accumulate in closed spaces. The hazards relating to these materials are associated with the FLASHPOINT of the liquid. This is the lowest temperature at which the liquid gives off vapor which accumulates near the surface in sufficient quantity to form a combustible mixture with air. Although liquid oxygen does not have a flashpoint, the explosive effect is the same. Almost any material that will oxidize becomes highly explosive when in the presence of liquid oxygen.

The flashpoint varies with specific materials. Personnel working with volatile materials should become familiar with the characteristics of the particular materials with which they are associated. They should know the flashpoint and also the concentration which constitutes a combustible mixture.

A general safety rule regarding explosive vapors is to always provide adequate ventilation so as to prevent accumulation of vapors, or to dispel accumulated vapors prior to operating electrical equipment in that space. The presence of an odor of gasoline or other flammable or explosive vapors is not a reliable indicator of flammability, since the ability to detect odors varies between observers.

Toxic Vapors

Some liquids, upon evaporating, produce vapors which are harmful to personnel. Carbon tetrachloride is an effective solvent, an excellent cleaning material, and an excellent fire extinguisher—but it produces vapors so toxic that its use for any purpose is specifically prohibited by Navy directives. Many other materials are either prohibited or very rigidly limited for use. In most instances, the precautions are listed on the container. These precautions must at all times be rigidly adhered to and enforced. Safe substitutable materials should be used whenever permissible.

Safety considerations require that all personnel make themselves familiar with the hazards involved in the use of all materials. Toxic materials and vapors may be easily detectable, or they may be almost completely undetectable; they may act very slowly, or they may act almost instantly; they may cause discomfort, temporary damage, permanent injury, or even death; they may or may not be explosive in addition to being toxic. Toxic vapors may produce headache, dizziness, nausea, and a general feeling of illness. They may cause a gradual loss of interest, energy, or awareness. They may result in unconsciousness. They may cause temporary or permanent damage to the respiratory system, eyes, or skin. They may cause paralysis or death. Avoid prolonged exposure to vapors not known to be safe.

CONFINED SPACES

When personnel are working in confined spaces, adequate ventilation must be provided. This includes oxygen for normal breathing, cooling to prevent heat exhaustion, air movement and exchange to prevent hazardous accumulations of vapors, and an additional or alternate source of ventilation for use in the event of emergency. Whenever a worker is sent into a confined space for any reason, provisions should be made in advance for his rescue in the event of accident or emergency. These provisions include the use of safety lines for locating the worker and for retrieving him from the space. Some means of communication must be established so that the conditions existing inside and outside the space may be made known to personnel concerned. A safety man must be provided to keep a constant check on the condition of the space and the worker, and he must be prepared to sound the alarm for additional help or to render assistance to the worker in the confined space, as required.

Fumes tend to collect in confined spaces, so the condition of the space should be checked prior to entry. The worker should also check conditions as he enters and monitor them during his stay. He should maintain constant communication with his safety man and inform him of any abnormal conditions that may exist.

Equipment used by personnel working in confined spaces is a matter of considerable importance. Enough light should be provided so that he can see clearly what he is doing. The light provided should be insulated so that it does not present a shock hazard (confined spaces are usually quite warm, and a safety light produces additional heat, so perspiration may become a serious problem). When possible, explosionproof equipment should be used in confined spaces, and protective clothing should be used if toxic fumes are known or suspected to exist within the space.

TOOLS

To prevent tragic and unnecessary damage to aircraft or equipment, loss of human life, or personal injury, it is necessary to develop and to practice careful, safe, and clean work habits. All tools and equipment used should conform to Navy standards as to quality and type, and should be used only in the manner and for the purpose intended. All tools in active use should be maintained in good repair, and all damaged or nonworking tools should be replaced through supply channels. When a job is completed, or when work is interrupted, all tools should be counted and returned to the toolboxes or to the tool issue room. This should be done as carefully as a surgeon accounts for all his instruments following a major operation.

Handtools

Detailed information on the use, care, and selection of general tools is contained in the Rate Training Manual, Basic Handtools, NavPers 10085-A. Chapter 7 of this manual presents information on specific tools used by avionics technicians. Appropriate study and frequent review of these sources are recommended for all personnel using or supervising the use of tools. The following paragraphs point out a few malpractices sometimes found among maintenance personnel.

Care should be taken in selecting the proper type pliers or cutters for the specific job. Pliers or cutters should not be used on nuts or pipe fittings—wrenches are made for this purpose. When cutting short pieces of wire, rivets, or other materials, take precautions so that the clippings do not fly and cause eye injury; wear goggles and be careful.

A screwdriver used for electrical work should have a nonconducting handle. Screwdrivers should never be used as a substitute for a punch, chisel, or prybar. The screwdriver selected should be of the proper type and size for the screw on which it is to be used. The tip of the screwdriver should be kept in the proper shape and condition—broken or defective screwdrivers should be discarded and replaced.

Wrenches should be used only if they are in good condition and if they are right for the job. Never use a wrench as a hammer, and never put an extension on the handle to increase torque. An adjustable wrench should be used so that the movable jaw is forward in the direction of turning. When working in close spaces, use a grip that will not endanger the fingers and knuckles if the wrench should slip.

Portable Power Tools

All portable power tools should be carefully inspected prior to use to insure that they are clean and in a proper state of repair. Switches should operate in a normal manner, cords should be free of defects, and the casings of all electrically driven tools should be properly grounded. When using or preparing to use any portable power tools, the cords, hoses, or cables should not be allowed to kink, nor should they be left where they may be run over or constitute a tripping hazard. They should not be allowed to come into contact with oil, grease, hot surfaces, chemicals, or sharp objects. When damaged, they should be replaced, never patched with tape.

Sparking electric power tools or equipment should never be used in any space where flammable vapors, gases, liquids, or explosives are suspected. When unplugging electrical tools or equipment from receptacles, first turn the equipment off, then grasp the plug (not the cord) to remove the plug from the receptacle. Stow the tool in its proper place.

ELECTRIC DRILL.—When using a portable power drill, grasp it firmly during operation to prevent bucking or breaking loose with possible injury to the user or damage to the tool or material. Use only straight, undamaged, and properly sharpened drill bits. Tighten the bit securely in the chuck, using the key provided (never tighten the chuck with wrench or pliers). The bit should be set straight and true in the chuck and the work firmly clamped. When drilling metal, the work should be marked with a center punch before beginning the drilling operation.

SOLDERING IRON.—The soldering iron is a fire hazard and a potential source of burns. Always assume that a soldering iron is hot; never rest the iron anywhere but on a metal surface or rack provided for that purpose. Keep the iron holder in the open to minimize the danger of fire from accumulated heat. Do not swing or flip the iron to dispose of excess molten solder—a drop may strike someone, or strike the equipment and cause a short circuit. Keep the head and hands away from the hot end of the iron; hold small soldering jobs with pliers or clamps. Position the ends of wires and cables so that they do not endanger the face or the eyes; never flip the wires to remove excess solder. When cleaning the iron, place the cleaning rag on a suitable surface and wipe the iron across it—do not hold the rag in the hand. Disconnect the iron when leaving the work, even for a short time—the delay may be longer than planned.

GROUNDING.—A poor safety ground, or one that is wired incorrectly, is more dangerous than no ground at all. The poor ground is dangerous because it does not offer full protection, while the user is lulled into a false sense of security. The incorrectly wired ground is a hazard because one of the line wires and the safety ground are transposed, making the shell of the tool "hot" the instant the plug is connected. Thus the unwary user is trapped, unless by pure chance the safety ground is connected to the grounded side of the line on a single-phase grounded system, or no grounds are present on an ungrounded system. In this instance the user again goes blithely along using the tool until he encounters a receptacle which has its wires transposed or a ground appears on the system. Because there is no absolutely foolproof method of insuring that all tools are safely grounded (and because of the tendency of the average person to ignore the use of the grounding wire), the old method of using a separate external grounding wire has been discontinued. Instead, a 3-wire, standard, color-coded cord with a polarized plug and a ground pin is required. In this manner, the safety ground is made a part of the connecting cord and plug. Since the polarized plug can be connected only to a mating receptacle, the user has no choice but to use the safety ground.

All new tools, properly connected, use the green wire as the safety ground. This wire is attached to the metal case of the tool at one end and to the polarized grounding pin in the connector at the other end. It normally carries no current, but is used only when the tool insulation fails, in which case it short circuits the electricity around the user to ground and protects him from shock. The green lead must never be mixed with the black or white leads which are the true current-carrying conductors.

Check the resistance of the grounding system with a low-reading ohmmeter to be certain that the grounding is adequate (less than 0.1 ohm is acceptable). If the resistance indicates greater than 0.1 ohm, use a separate ground strap.

Some old installations are not equipped with receptacles that will accept the grounding plug. In this event, use one of the following methods:

1. Use an adapter fitting.

2. Use the old type plug and bring the green ground wire out separately.

3. Connect an independent safety ground line. When using the adapter, be sure to connect the ground lead extension to a good ground. (Do not use the center screw which holds the cover plate on the receptacle.) Where the separate safety ground leads are externally connected to a ground, be certain to first connect the ground and then plug in the tool. Likewise, when disconnecting the tool, first remove the line plug and then disconnect the safety ground. The safety ground is always connected first and removed last.

GENERAL HAZARDS

In addition to the specific hazards encountered in electronic maintenance and the obvious dangers involved in falling, tripping, slipping, colliding, etc., the technician is concerned with other general classes of hazards. The following paragraphs, although by no means a complete coverage, will present some pertinent details and general information concerning a few of the most important ones.

FIRE AND EXPLOSION

Although fire and explosion are frequently associated with one another, they may also exist separately. Considerable detail on these subjects is included in Basic Military Requirements, NavPers 10054-B. Study and review of this material will provide a foundation for the specific information presented in this part of this chapter. Information is available in other Rate Training Manuals, including the following: Seaman, NavPers 10120-E; Airman, NavPers 10307-C; Military Requirements for Petty Officer 3 & 2, NavPers 10056-C; and Standard First Aid Training Course, NavPers 10081-B.

Fire

A general discussion of the nature of fire, the classes of fires, firefighting systems and equipment, protective clothing and equipment, and fire prevention is contained in chapter 14 of the Rate Training Manual, Basic Military Requirements, NavPers 10054-B. General information concerning aircraft crash rescue and firefighting is found in Airman, NavPers 10307-C. Specific details relating to firefighting and rescue procedures for a particular model aircraft may be found in the technical manuals published for that model aircraft. Standard First Aid Training Course, NavPers 10081-B, contains general procedures for the rescue of personnel from fire and first aid treatment for fire victims. A thorough study and a review of these references are an obligation of all personnel. Since this material is found in publications which are generally available to naval aviation personnel, it is not presented in detail in this manual. However, some details of special interest are summarized in the following paragraphs.

In the case of electrical fires, the following steps should be taken:

1. Deenergize the electrical circuit involved, and any other electrical circuits that may interfere with the proper control or extinguishing of the fire, or which may constitute a hazard to the firefighters.

2. Call the fire department. This should be done even if it is a "small fire" that can be "easily" controlled or extinguished. This is a precautionary measure to be taken in the event of unforeseen complications or miscalculation.

3. Attempt to control or extinguish the fire if possible, using the appropriate fire extinguisher and firefighting procedure.

4. Make a full report on the fire to the appropriate authority. The fire marshal has complete information as to the proper forms and reports, and should be contacted for assistance if needed. However, this does not relieve the person discovering the fire from his responsibility in this matter.

For combating electrical fires, a CO_2 (carbon dioxide) fire extinguisher is best. The carbon dioxide should be directed to the base of the flame, where it will serve two purposes: It cools the area, and it decreases the percentage of oxygen present at the fire. However, for major fires of any type in confined spaces, the excessive use of carbon dioxide may be dangerous, due to the decreasing of oxygen content.

Carbon tetrachloride should not be used for firefighting, because it is converted into phosgene gas (a deadly poisonous gas) upon contact with hot metals. Even in open spaces this gas creates a serious hazard, and the use of carbon tetrachloride is specifically prohibited.

Application of water to electrical fires may be dangerous to personnel and injurious to equipment, because of the electrical conductivity of water and the corrosive properties of water when used on metallic substances.

Foam type fire extinguishers should not be used on electrical fires because the foam is electrically conductive.

Avoid inhaling flames or smoke from fires, as these may cause serious injury or death if breathed to excess.

Special precautions must be taken if the fire is in an enclosed or confined space. Local regulations will detail the appropriate procedures to be followed in this event.

In the case of cable fires in which the inner layers of insulation (or insulation covered by armored or shielded cable) are burning, the only positive method of preventing the fire from running the length of the cable is to cut the cable and separate the ends.

Fumes of an explosive, toxic, or corrosive nature are generated in the combustion of certain substances. This will be discussed in a later portion of this chapter.

Explosion

Explosion may be caused by fire or may be the cause of a fire—or the two may be unrelated. It may be the result of a chemical action, heat, mechanical malfunction, or other causes. An explosion is generally accompanied by a loud noise and a sudden buildup of pressure. Several types of explosions are of interest to the technician in the performance of his normal duties.

The accumulation of combustible fumes or vapors from fire or from evaporating liquids represents a potential hazard. A spark or increase in heat from any cause or certain chemical combinations, may trigger the explosion.

An explosion in the presence of fire may result in the rapid spread of that fire. An explosion in the presence of combustible materials may cause a fire to start.

An explosion may result in flying debris which will act as shrapnel and may cause severe personnel injuries. In the event of severe explosion, nearby personnel may suffer from the concussion effect of the blast.

In addition to the fire-caused accumulation of combustible vapors and the accumulation of combustible gases in the vicinity of fire or electric sparking, there are several other explosion hazards. A few of these are discussed in the following paragraphs.

Some equipments are pressurized and are susceptible to explosion in the event of excessive pressurization or mechanical failure of any part of the pressurized system. In this event, the major hazard of the explosion is the creation of shrapnel, or the increased danger of arcing in the absence of the pressurization. Implosion, like explosion, results in creation of shrapnel, frequently with toxic materials coating the splinters. The rapid collapse of glass vacuum tubes is an example of implosion which is of prime importance to electronics personnel.

Explosive ordnance devices are sometimes installed on aircraft or placed adjacent to the aircraft preparatory to loading. Accidental operation of switches may result in the firing of these devices. The technician, when operating any equipment in the aircraft, must keep himself constantly aware of any electrically initiated ordnance devices in the vicinity of his aircraft, and must observe all precautions which apply to the situation. When missiles or weapons are installed, only fully qualified personnel should be permitted to operate any electronic equipment in the aircraft. A definite possibility of detonation of ordnance devices by radiated RF energy is also known to exist. This hazard is discussed later in the chapter under RF radiation hazards.

FUMES

The term FUMES refers to vapors, gases, or smoke, especially those that are strong or dangerous, or which have a potent odor. For purposes of this discussion, fumes may be classified as toxic, explosive, corrosive, poisonous, suffocating, or irritating. They may result from fire, evaporating liquids or solids, chemical action, or overcrowding in confined or poorly ventilated spaces. They may be easily detectable, or almost impossible to detect. They may represent a single hazard, or they may represent a combination of several distinct hazards.

Fuels

The vapors from nearly all hydrocarbon fuels present hazards of fire and explosion as previously discussed; in addition, they are toxic. When breathed in heavy concentration, or for prolonged periods, they may result in permanent damage to the respiratory system, loss of consciousness, paralysis, and/or death. For these reasons, numerous safety regulations and detailed procedures have been issued regarding fuels and fueling operations. In general, the most important of these regulations require rigid enforcement of the NO SMOKING rules, adequate ventilation, restrictions on the use of electrical equipment, use of special equipment, and the presence of manned firefighting equipment.

Painting Supplies and Materials

Most paints and thinners, and many other painting supplies, emit vapors which are both flammable and toxic. Regulations require these items to be stored in closed containers in a noncombustible enclosure isolated from living, working, or ordinary storage spaces. Use of the material is restricted to well-ventilated areas, and in many cases, special equipment and clothing are made available for use.

Battery Fumes

In the standard lead-acid storage battery, explosive fumes are generated by chemical action. In the charging operation, hydrogen is released. Hydrogen is a highly combustible gas, which is violently explosive when in strong concentration. The newer nickel-cadmium batteries do not present this hazard, but do present other hazards as covered in a later discussion. Battery lockers are subject to very strict safety regulations with special emphasis on smoking restrictions and ventilation requirements.

Smoke

Smoke, a byproduct of fire, represents a toxic and suffocating hazard. In addition, there are other fumes frequently present in smoke. These fumes, products of combustion or of increased evaporation, may be poisonous, corrosive, or explosive. It has been previously mentioned that carbon tetrachloride, upon coming into contact with hot metals, is converted into deadly phosgene gas. There are many other materials which are converted by heat or combustion from relatively harmless substances into lethal fumes.

Carbon monoxide is present in nearly all smoke, and is the most common cause of "smoke poisoning" among firefighters and fire victims. Unless the victim is removed from the smoke and administered artificial respiration and/or oxygen, death may result.

The use of gas masks, breathing apparatus, and safety lines is prescribed under certain firefighting situations.

Miscellaneous Materials

Many other general classes of materials contain substances which produce hazardous fumes. These materials should be used only according to specified procedures. Some of these material classes are cleaning materials, insecticides, preservatives, solvents, adhesives, and finishes.

Although not technically classified as fumes, dust and small particles from grinding operations present similar hazards and require precautions similar to those taken for fumes.

CHEMICALS

The subject of chemical warfare (and its agents, treatments, and preventive measures) is treated in detail in other Rate Training Manuals for which the prospective PO3 or 2 is responsible. Among these manuals are Basic Military Requirements, NavPers 10054-B; Military Requirements for Petty Officer 3 & 2, NavPers 10056-C; and Standard First Aid Training Course, NavPers 10081-B.

RADIOACTIVITY

Radioactive materials are in common usage throughout the Navy, and particularly in the electronics field. Common radioactive materials familiar to most technicians include the luminous dials on watches and various instruments, and the luminescent markings on equipment. Radioactive material is intentionally added to many special purpose electron tubes to produce a continuous supply of ionized particles to insure that the tube will always ionize at the same voltage. The principal radioactive materials contained in these tubes include certain isotopes of carbon (C^{14}), cesium (Cs^{137}), cobalt (Co^{60}), nickel (Ni^{63}), and radium (Ra^{226}). These tubes are usually the TR and ATR tubes, glowlamp and cold cathode type tubes, and certain spark gap tubes. With proper precautions and procedures, these materials present no serious hazard; with careless or improper treatment, however, the hazard may become very serious.

Radioactive materials emit rays which may cause changes in living tissue with subsequent injury to the body. The amount of change, and therefore the seriousness of the injury, increases with the amount of radiation absorbed. The absorption of radiation is cumulative, and the repair of damaged tissue is slow; therefore, the hazard level is based on the total amount of radiation absorbed as well as on the rate of absorption.

The primary hazard considered in this discussion is injection of radioactive substances into the bloodstream through a cut or an abrasion, or through penetration of the skin by glass slivers from broken tubes. This type injury may be quite serious, even with minute quantities of radioactive materials injected. The materials injected are carried throughout the body by the bloodstream, and tend to accumulate in certain organs or parts of the body. In addition to the radiation effects, they also cause a type of poisoning similar to chemical poisoning.

A wound caused by a radioactive particle requires treatment by a medical officer as soon as possible, regardless of the size of the wound. The hazard of radioactive particles being left in a wound CANNOT BE IGNORED.

There are no known antidotes for poisoning from radioactive particles which remain in the body. Treatment of radiation sickness is complicated and lengthy. Even with the best medical attention, the results are often inconclusive. However, progress continues in this field and close liaison with the medical department will insure that the latest first aid procedures and medical treatment are used.

Inhalation of minute particles of radioactive dust can cause coating of the mucous membranes, with resultant poisoning and increased radiation effects. Once lodged in the nasal passages or throat, these particles are very difficult to remove—in the lungs they are even more difficult.

Contamination of the skin by radioactive materials may produce radiation burns resembling the temporary redness of a mild sunburn (or in severe cases, a serious flame burn which destroys the skin). All such cases should be reported to the medical authorities immediately; with proper medical care, complete recovery may be expected except in extreme cases involving severe burns over an extensive area. This type injury is rare.

Detection

Radioactive radiation is completely undetectable through use of the human senses; detection relies upon the use of special equipment. The methods of detection and the types of radioactivity detectors are discussed in chapter 15 of the Rate Training Manual, Basic Military Requirements, NavPers 10054-B. Coverage of the subject in this course is limited to a brief discussion of the various conditions and places which require monitoring.

Storage areas containing instruments, equipments, or tubes with radioactive materials should be monitored periodically to insure that the radiation level does not exceed allowable limits. Specifically, the air intake and exhaust screens or filters should be monitored prior to cleaning. All areas surrounding the breakage of any tube containing radioactive material, or the flaking of radioactive paint or markings, should be monitored to help locate all the radioactive material. These areas should be monitored again following decontamination to determine the effectiveness of the procedures used. Personnel should be monitored whenever contact with radioactive materials is suspected, or following participation in decontamination activities.

Precautions

The following safety practices should be observed to minimize the hazard presented by radioactive materials:

1. Tubes or instruments should not be removed from cartons until immediately prior to actual installation. This serves two purposes—to prevent accidental breakage, and to avoid the possibility of concentrating several radioactive sources in a small volume (which would increase the effective intensity of radiation).
2. When a radioactive component is removed from equipment, it should be placed in an appropriate carton to prevent possible breakage.
3. Items containing radioactive materials should never be carried in a pocket or elsewhere about the person in a manner that flaking or breakage can occur.
4. Extreme care should be exercised in the handling of these items while installing or removing them from equipment.
5. Tubes should never be broken intentionally; however, if breakage does occur, material contaminated by radioactivity should not be allowed to come in contact with any part of the body at any time. Take care to avoid breathing any dust or vapor (such as radon gas, a highly radioactive substance) which may be released

by such breakage. Immediately locate all broken pieces, and isolate the area until the broken pieces have been removed or declared nonradioactive by test with an adequate radiation-sensitive device.

6. No food or drink should be brought into the contaminated area or near any radioactive material.

7. Immediately after leaving a contaminated area, personnel who have handled radioactive material in any way should remove contaminated clothing. They should wash their hands and arms thoroughly with soap and water, especially before eating, drinking, or smoking.

8. When a wound caused by a sharp radioactive object is sustained, report to medical authorities for treatment as soon as possible.

Decontamination and Disposal

When cleaning a contaminated area, rubber or plastic gloves should be worn. Large fragments of a broken tube should be removed with the aid of some tools such as forceps, if they are available. The remaining particles can be removed with a vacuum cleaner, using a disposable collecting bag, or by wiping a wet cloth across the area. (If the breaking of tubes is a frequent occurrence, care should be given to selecting the best type of collecting bags.)

If a wet cloth is used, make one stroke at a time, and fold the cloth in half after each stroke, always using a clean side. When the cloth becomes too small, discard it and continue with a clean piece. Be careful not to rub the radioactive particles into the surface by using a back-and-forth motion. All debris, cloths, and bags used for cleaning should be sealed in a container such as a plastic bag, heavy waxed paper, or a glass jar, and placed in a steel can for disposal.

Radioactive waste materials and sweeper bags should not be disposed of individually. They should be collected in a designated steel container with a tight-fitting lid and suitable markings until a reasonable quantity for disposal has been gathered. Containers for radioactive materials should be marked with the radiation symbol. (See fig. 2-1.) The symbol is printed in magenta (purplish shade of red) color on a yellow background.

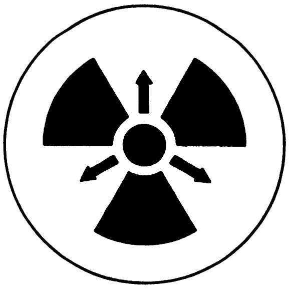


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Figure 2-1.—Radiation symbol.

Radioactive waste can be disposed of by burying in soil or by sinking in the ocean. Detailed information concerning the disposal of radioactive materials is contained in BuShips Instruction 5100.15.

MAINTENANCE HAZARDS

Every person who works with electronic equipment should be constantly alert to the hazards of the equipment to which he may be exposed, and also be capable of rendering first aid to injured personnel. The installation, operation, and maintenance of electronic equipment requires enforcement of a stern safety code. Carelessness on the part of the operator or the maintenance technician can result in serious injury or death due to electric shock, falls, burns, flying objects, etc. After an accident has happened, investigation almost invariably shows that it could have been prevented by the exercising of simple safety precautions and procedures with which the personnel should have been familiar.

Each man concerned with electronic equipment should make it his personal responsibility to read and become thoroughly familiar with the safety practices and procedures contained in applicable safety directives, manuals, and other publications, and in equipment technical manuals prior to performing work on electronic equipment. It is the individual's responsibility to identify and eliminate unsafe conditions and unsafe acts which cause accidents.

GENERAL PRECAUTIONS

Take time to be safe when working on electronic circuits and equipment. Carefully study the schematics and wiring diagrams of the entire system, noting what circuits must be deenergized in addition to the main power supply. Remember that electronic equipments frequently have more than one source of power. Be certain that ALL power sources are deenergized before servicing the equipment. Do not service any equipment with the power on unless it is necessary.

It must be borne in mind that deenergizing main supply circuits by opening supply switches will not necessarily "kill" all circuits in a given piece of equipment. A source of danger that has often been neglected or ignored—sometimes with tragic results—is the inputs to electronic equipment from other sources, such as synchros, remote control circuits, etc. For example, turning off the antenna safety switches will disable the antenna, but it may not turn off the antenna synchro voltages from other sources. Moreover, the rescue of a victim shocked by the power input from a remote source is often hampered because of the time required to determine the source of power and turn it off. Therefore, turn off ALL power inputs before working on equipment.

Remember that the 115-volt power supply voltage is not a low, relatively harmless voltage, but is the voltage that has caused more deaths in the Navy than any other.

Do NOT work with high voltage circuits by yourself; have another person (safety observer), who is qualified in first aid for electrical shock, present at all times. The man stationed nearby should also know the circuits and switches controlling the equipment, and should be given instructions to pull the switch immediately if anything unforeseen happens.

Always be aware of the nearness of high voltage lines or circuits. Use rubber gloves where applicable, and stand on approved rubber matting (MIL-M-15562). Not all so-called rubber mats are good insulators.

Equipment containing metal parts, such as brushes and brooms, should not be used in an area within 4 feet of high voltage circuits or any electric wiring having exposed surfaces.

Inform remote stations as to the circuit on which work is being performed.

Keep clothing, hands, and feet dry if at all possible. When it is necessary to work in wet or damp locations, use a dry platform or wooden stool to sit or stand on, and place a rubber mat or other nonconductive material on top of the wood. Use insulated tools and insulated flashlights of the molded type when required to work on exposed parts.

Do not wear loose or flapping clothing. The use of thin-soled shoes with metal plates or hobnails is prohibited. Safety shoes with nonconducting soles should be worn if available. Flammable articles, such as celluloid cap visors, should not be worn.

When working on electronic or electrical apparatus, technicians should first remove all rings, wristwatches, bracelets, ID chains and tags, and similar metal items. Care should be taken that the clothing does not contain exposed zippers, metal buttons, or any type of metal fastener.

Do NOT work on energized circuits unless absolutely necessary. Be sure to take time to lock out (or block out) the switch and tag it. Locks for this purpose should be readily available; if a lock cannot be obtained, remove the fuse and tag it.

Use one hand when turning switches on or off. Keep the doors to switch and fuse boxes closed except when working inside or replacing fuses. Use a fuse puller to remove cartridge fuses after first making certain that the circuit is dead.

All supply switches or cutout switches from which power could possibly be fed should be secured in the OPEN (safety) position and tagged. The tag should read "THIS CIRCUIT WAS ORDERED OPEN FOR REPAIRS AND SHALL NOT BE CLOSED EXCEPT BY DIRECT ORDER OF . . ." (the person making, or directly in charge of, repairs).

Never short out, tamper with, or block open an interlock switch.

Keep clear of exposed equipment; when it is necessary to work on it, use one hand only as much as possible.

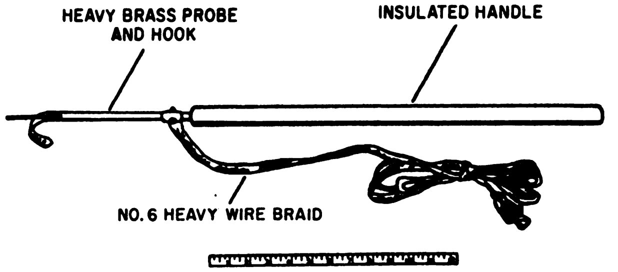
Warning signs and suitable guards should be provided to prevent personnel from coming into accidental contact with high voltages.

Avoid reaching into enclosures except when absolutely necessary; when reaching into an enclosure, use rubber blankets to prevent accidental contact with the enclosure.

Do not use bare hands to remove hot tubes from their sockets. Use asbestos gloves or a tube puller.

Use only rubber or insulated hose on air lines for blowing out equipment. Use no more than 10 psi to avoid damage to the insulation and/or components. Use only moisture free air. Never turn compressed air on yourself or others, since it could cause serious injury.

Use a shorting stick, similar to the one shown in figure 2-2, to discharge all high voltage charges. Before a worker touches a capacitor or any part of a circuit which is known or likely to be connected to a capacitor (whether the circuit is deenergized or disconnected entirely), he should short circuit the terminals to make sure that the capacitor is completely discharged.



AT.14

Figure 2-2.—Shorting stick.

DEGREE OF SHOCK

The amount of current that may pass through the body without danger depends on the individual and the current quantity, the type, path, and length of contact time.

Body resistance varies from 1,000 to 500,000 ohms for unbroken, dry skin. Resistance is lowered by moisture and is highest with dry skin. Breaks, cuts, or burns may lower body resistance to 200 ohms. A current of 1 milliampere can be felt and will cause a person to avoid it. Five milliamperes is about the highest current safe for the average body. If the palm of the hand makes contact with the conductor, a current of about 12 milliamperes will tend to cause the hand muscles to contract, freezing the body to the conductor. Such shock may or may not cause serious damage, depending on contact time and personal physical condition, particularly the condition of the heart. A current of only 25 milliamperes has been known to be fatal.

Generally, currents between 100 and 200 milliamperes are lethal. Ventricular fibrillation of the heart occurs when the current through the body approaches 100 milliamperes. Ventricular fibrillation is the uncoordinated actions of the walls of the heart's ventricles. This in turn causes the loss of the pumping action of the heart. Fibrillation is usually fatal because people who are qualified to administer appropriate treatment are not available to administer treatment soon enough.

If currents of 200 milliamperes or higher pass through the body, severe burns and unconsciousness result. Generally, in these cases the heart will not fibrillate but will be stopped. It may be started again by closed chest heart massage; or if breathing has also stopped; the heart may spontaneously restart if artificial resuscitation brings the blood oxygen supply to a high enough level. In any case, where breathing has stopped, artificial resuscitation should be started immediately.

When a person is rendered unconscious by a current passing through the body, it is impossible to tell how much current caused the unconsciousness. Artificial respiration must be applied immediately if breathing has stopped and continued until otherwise directed by medical authority.

SPECIAL COMPONENTS

In addition to the general hazards and precautions listed previously, several components common to aviation electronic maintenance present hazards or potential hazards. The following paragraphs present a brief summary of some of the more important of these components and their hazards.

Selenium Rectifiers

When selenium rectifiers burn out, fumes of selenium dioxide are liberated, causing an overpowering stench. The fumes are poisonous and should not be breathed. If a rectifier burns out, deenergize the equipment immediately and ventilate the compartment. Allow the damaged rectifier to cool before attempting any repairs. If possible, move the equipment containing it out of doors. Do not touch or handle the defective rectifier while it is hot, since a skin burn might result, permitting some of the selenium compound to be absorbed.

Batteries

Battery hazards are most common during the charging process and during the installation and removal process. The weight and clumsiness of the battery contribute to the strain hazard; commonsense and routine attention to detail minimize this hazard. All rechargeable storage batteries should be charged in strict accordance with the manufacturer's recommendations.

LEAD-ACID.—Lead-acid storage batteries present hazards of acid burn, explosion, and strain. Burns may be prevented by the proper use of eyeshields, rubber gloves, rubber aprons, and rubber boots with nonslip soles. This protective clothing should be worn whenever refilling, checking, transporting, or charging batteries. Explosion may result from accumulation of hydrogen gas during charging operation. Proper ventilation and strict enforcement of the no smoking rules are mandatory.

NICKEL-CADMIUM.—The electrolyte used in nickel-cadmium (NiCad) batteries is potassium hydroxide (KOH), a highly corrosive alkaline solution which should be handled with the same degree of caution as sulfuric acid. If KOH is sprayed on any material, wash it immediately with liberal quantities of water and neutralize the affected area with vinegar or a weak solution of acetic acid.

An extremely violent explosion would occur if KOH were added to a lead-acid battery or if sulfuric acid were added to a NiCad battery. Although there is no valid excuse for such an occurrence, inattention to detail can make it possible. All battery electrolytes should be kept in clearly marked containers and should, if possible, be kept in different storage areas when not in use.

MERCURY CELL.—Under certain conditions, mercury dry cells or batteries may explode. The most common cause of explosion is overloading the battery (with the subsequent heating and ignition of hydrogen gas within the cell). The loading capacity of the battery is decreased as the battery is discharged. When a mercury cell (or any cell within a mercury battery) has discharged to 70 percent of its nominal voltage, the cell or battery should be replaced. Discharged mercury batteries should never be stored; holes should be punched in the steel jacket and the battery discarded.

Cathode-Ray Tubes

Extreme caution should be exercised in handling a cathode-ray tube (CRT). The glass envelope encloses a high vacuum; and because of the large surface area, the envelope is subjected to considerable total force due to atmospheric pressure. (See chapter 5 of this manual for a discussion of total force and pressure.)

The trend toward the use of larger CRT's has increased the hazard of IMPLOSION (collapse of the glass tubes as a result of atmospheric pressure). The tubes are not considered hazardous if handled properly; but if they are struck, scratched, dropped, or handled improperly in any way, they may become an instrument of severe injury or death.

When handling, installing, or removing a CRT, use extreme care to avoid contact between the tube and any sharp or hard object. Wear suitable gloves to protect the hands. Wear goggles to protect the eyes from flying glass particles in the event of implosion. The goggles should provide both side and front protection, and should have clear lenses that can withstand a rigid impact. Insert the tube carefully into the socket, using only moderate pressure. Do not jiggle the tube. Never hold it by the narrow neck. Do not stand directly in front of the face of the tube; accidental implosion may cause the electron gun or other parts to be propelled directly forward with sufficient velocity to cause severe injury. When the tube must be set down, it is important that the face be placed gently on a thick, clean, soft padding.

In addition to the hazard of implosion, rough handling may also result in displacement of the electrodes within the tube and result in faulty operation or nonoperation of the tube.

The chemical coating material on the face of the tube may be extremely toxic. When disposing of a broken tube, use protective devices and procedures to insure that none of this compound gets on the hands or into the skin.

Before a CRT is discarded, the danger of implosion must be eliminated. Place the defective tube face down in an empty CRT carton, carefully break off the locating pin from the tube base, and (using a small screwdriver, pliers, or a probe) break off the tip of the glass vacuum seal. (See fig. 2-3.) With the vacuum seal broken, pressure inside and outside the tube becomes equalized, and the danger of implosion is removed. However, all other hazards still remain.

Dielectric Materials

The increasing use of microwave energy and the accompanying increase in power levels have given rise to several significant problems.

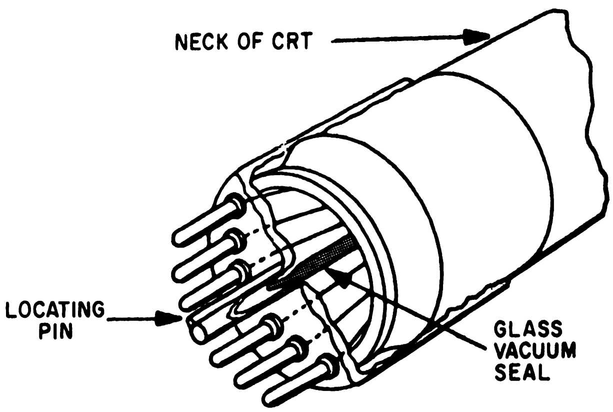


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Figure 2-3.—Construction of cathode-ray tube base.

Among the problems which have arisen are those resulting from the use of certain dielectric materials in new environments without previous application experience. In several cases situations have developed in which personnel were exposed to potentially toxic agents as a direct result of the introduction of new substances about which little toxicological information was available.

One example is the use of sulfur hexafluoride (SF_4) as a gas dielectric to increase power handling capability of waveguides. In its pure state, this gas is essentially inert and nontoxic. However, when arc-over occurs in a waveguide filled with the gas, decomposition products constitute a toxic gas hazard. These toxic gases, which include fluorine, may not irritate the skin, are colorless, and cannot be detected by odor. However, they may cause extreme lung irritation and hemorrhaging.

Arcing may take place periodically in the waveguide until the system fails completely, or at least until system performance drops below an acceptable minimum level. If a maintenance technician should open the waveguide while effecting repairs on the system, he may release these highly toxic agents.

When opening a waveguide pressurized with sulfur hexafluoride, personnel should use approved respiratory protective devices. All such work should be accomplished in a well-ventilated space, and the area should be cleared of all toxic hazard before allowing other personnel to enter the area.

As toxicological or other information regarding safety matters becomes available, precautionary measures and protective devices are developed, distributed, and promulgated. Until it has been ascertained that a new material or substance is completely safe, precautionary measures should be used as if definite hazards were known to exist.

RF RADIATION

Electromagnetic radiation is not visible; its presence must be detected and measured by instruments or approximated by theoretical calculations. Radiated beams of high power RF energy present a health and safety hazard. In general, health and safety factors fall into the ordnance, personnel, fuel, and miscellaneous aspects. The establishment of health and safety precautions regarding electromagnetic radiation is a joint responsibility of the Bureau of Medicine and Surgery, the Naval Air Systems Command, and the Naval Ship Systems Command. Publications which may prove valuable for further reference include Radio-Frequency Hazards Manual, NavWeps 16-1-529 (a Confidential manual), and Electronics Installation and Maintenance Book - Test Methods and Practices, NavShips 100,000.103.

The energy striking an object in an electromagnetic field may be reflected, transmitted, or absorbed; only the absorbed energy constitutes a hazard. The hazard resulting from focused concentration of such energy, like any hazard, can be rendered relatively harmless by understanding and precaution.

ORDNANCE HAZARDS

The hazards of electromagnetic radiation to ordnance (HERO) problem has become acute. The number and variety of electrically initiated explosive devices are increasing rapidly. For example, some currently operational weapons contain more than 75 electroexplosive devices. Continuing development efforts are directed toward reducing weight and space requirements, lowering power requirements, assuring positive response, and increasing safety and reliability. However, these goals are not always complementary.

At the same time, the power of communications and radar transmitting equipment is constantly being increased and the frequency spectrum broadened. The radiofrequency spectrum now used by the airborne Navy extends from 10 kHz to about 20,000 MHz. Transmitter power outputs extend to 10 kw at communications frequencies, and peak power outputs extend to approximately 5 megawatts at radar frequencies.

These trends produce situations which are in direct conflict with each other. On the one hand, transmitters and their antennas have only one purpose—to radiate electromagnetic energy. The initiating elements of ordnance devices need only to be supplied with the proper amount of electrical energy for an explosion to take place. Therefore, with many explosive ordnance items, certain precautions are required for safety and to insure reliable performance.

To meet the growing need for new procedures to reduce the hazard to ordnance equipment from RF radiation, the Naval Air Systems Command has sponsored tests which, coordinated with studies made by other agencies, have provided new guidelines and restrictions for handling electrically initiated ordnance equipment.

The basic problem in determining an ordnance systems' susceptibility to RF radiation lies in the evaluation of the antennalike couplings that exist between illuminating fields and the electroexplosive devices in the system. RF energy may enter a weapon as a wave radiated through a hole or crack in the weapon skin, or it may be conducted into the weapon by the firing leads or other wires leading into the weapon.

The exact chances of electroexplosive device firing are quite unpredictable, being dependent upon such variables as frequency, field strength, positional and directional orientation, environment, and metallic or personnel contacts with the ordnance or aircraft.

The most susceptible period is during assembly, disassembly, loading, unloading, or testing in electromagnetic fields. The most likely effects of premature actuation are dudding, reduction of the reliability of the device, or propellant ignition. In extreme cases, there is a definite possibility of warhead detonation.

Some specific safety precautions which the technician must observe with respect to these weapons and ordnance devices include the following:

1. Turn off all RF transmitters during weapon handling operations in the area.
2. Observe all local and general safety and HERO restrictions.
3. Maintain radio and radar silence during assembly, disassembly, loading, unloading, or testing operations.
4. Avoid illumination of ordnance devices by high power RF transmitters.

The HERO problem is a complex one. The hazard, and therefore the solution, is a function not only of frequency and field strength, but also of geometrical configuration, orientation, and the antenna characteristics of the weapon or weapon-aircraft and weapon-launcher combinations. In general, the path by which energy is introduced to the electroexplosive devices is not readily defineable.

Development projects are underway in several areas to provide special devices and material which will have general application as HERO remedies. It is expected that some of these devices, and some developed by other agencies, will be valuable in the design of new weapons as well as modifications for existing weapons. Many possibilities have been and are being explored. These include shielding, filters, RF dissipating attenuators, less sensitive electroexplosive devices, exploding wires, conductive film igniters, spark gap primers, inductive firing devices, and modifications to aircraft armament circuits.

PERSONNEL HAZARDS

Development of RF systems with high power transmitting tubes and high gain antennas has increased the hazard to personnel in the vicinity of these elements. Harmful effects of overexposure to RF radiation are associated with the average power of the absorbed radiation. They are thermal in nature, and are observed as an increase in overall body temperature or as a temperature rise in certain sensitive organs of the body. The only known nonthermal effects on personnel are due to power density values considerably greater than the power densities normally associated with present RF transmitting systems.

The Bureau of Medicine and Surgery has established safe limits based on the power density of the radiation beam and the exposure time of the human body in the radiation field. All areas in which the RF levels exceed the safe limits are considered hazardous. The Naval Ship Systems Command is responsible for determining hazardous shipboard areas and for decreasing the hazard to personnel from RF radiation. Theoretical calculations and power density measurements are used to establish the distances from radar antennas within which it is not biologically safe for personnel to enter. This information is then used to determine if and where hazardous areas exist. All hazardous areas subject to entry by personnel are posted with warning signs, and the ship's intercommunication system is used to warn personnel when the radars are operating.

Personnel Safety Precautions

While every effort must be made to protect personnel from harmful exposure to RF radiation, it is not considered necessary or desirable, in general, that blanket restrictions on antenna radiation be imposed to achieve this end. The existence of such a policy would tend to restrict maintenance and checkout procedures which could otherwise be carried out in safety, provided proper precautions are taken to keep personnel clear of hazardous intensity levels. These precautions include the following:

1. Visual inspection of feed horns, open ends of waveguides, and openings emitting RF electromagnetic energy must not be made unless the equipment is definitely secured for the purpose of such an inspection.
2. Aircraft employing high power radar should be parked, or their antennas should be oriented, so that the beam is directed away from personnel working areas.
3. All personnel must observe RF hazard warning signs which point out the existence of RF radiation hazards in a specific location or area.
4. Those radar antennas which normally rotate are to be rotated continuously while radiating, or trained to a known safe bearing.
5. Nonrotating antennas must be trained and elevated away from inhabited areas, hangars, shop spaces, ships, piers, etc., while radiating.
6. Where a possibility of accidental overexposure might still exist, have a man stationed within view of the antenna (but well out of the beam and in communication with the operator while the antenna is radiating) to warn personnel of the hazard.
7. Radiation hazard warning signs should be available and must be used, not only where they are required to be permanently posted, but also where they may temporarily restrict access to hazardous areas.
8. Table 2-1 generalizes the relationship between transmitter power and safe distance for personal exposure of 1 hour or more. It is thus applicable to many types of transmitters.

Table 2-1.—Transmitter power versus safe distance.

Rated power of transmitter	Distance (feet)
50 watts or less	15
51 to 200 watts	25
201 to 1,000 watts	50
Over 1,000 watts	75

FUEL HAZARDS

The increase in radiated RF energy from higher powered communications and radar equipments in recent years has increased the potential hazard of RF-induced ignition of volatile fuel-air mixtures. This flammable condition is normally present only close to aircraft fuel vents, open fuel inlets, or spilled fuel, or during over-the-wing fueling operations. Ignition of fuel vapors in air has actually occurred; however, the probability of ignition with normal refueling conditions is remote.

Ignition of gasoline vapors caused by RF-induced arcs is rare because ALL the following conditions must exist:

1. A flammable fuel-air mixture must be present within the range of the induced arcing.
2. The arc must contain a sufficient amount of energy to cause ignition.
3. The gap across which the arc occurs must be a certain minimum distance, and must contain a sufficient amount of the flammable mixture to ignite. The possibility of these conditions occurring simultaneously is probably statistically remote; but since the possibility does exist, care must be exercised.

MISCELLANEOUS ASPECTS

The firing of photoflash bulbs, fluorescent lamps, and neon glowlamps by electromagnetic energy from radar sets is a fairly well known phenomenon. Although this type occurrence is normally of little consequence, burns can result. Photographic personnel should be warned of the presence of any high power radar operating in the area and of the hazards involved.

In a similar manner, steel wool may be set afire, or metallic chips may produce sparks when exposed to radiation. With some high power radar sets, steel wool is ignited with a violent explosion. The presence of oils and spilled fuels in the vicinity of aircraft constitutes a serious hazard. This makes good housekeeping procedures essential.

PERSONNEL INJURIES AND SAFETY EDUCATION

The primary purpose of any safety education program is the PREVENTION of personnel injuries or material damage. For any safety program to be effective, all personnel must be aware of the potential hazards present, and they must observe all necessary precautions at all times. This part of the overall safety education program may be best directed by specially qualified personnel in each aspect of safety, or by a safety engineer if one is available.

A second, but vital, aspect of the safety education program is FIRST AID. This part of the program is usually under the direction of Medical Department personnel.

Since a complete training course of this type is quite time consuming, the most immediate requirement is to instill into all personnel a constant awareness of their actions and their surroundings. This awareness, and commonsense, are absolute essentials—without them no safety education program can be effective. The instilling and maintaining of these characteristics is best promoted by coworkers and immediate supervisory personnel.

CHAPTER 3

TOOLS AND MATERIALS

A skilled technician can be identified by the way he handles and cares for his tools and materials. Tools are a costly investment and should be cared for and used to full advantage. There seems to be something about a good tool that helps the average technician turn out better than average work. This fact alone more than justifies the slightly higher cost of quality tools. Even more important is the fact that low quality tools become defective more readily and can result in injury to the user or damage to the equipment undergoing repair.

In the same manner, proper use of quality materials improves the quality of any maintenance task and reduces the possibility of new failures. It is the responsibility of all maintenance personnel to become thoroughly familiar with the tools and materials of his trade and be proficient in their care and use.

HANDTOOLS

For purposes of this discussion, the term "handtools" will be used to refer to the small portable or fixed power tools commonly available in electronics maintenance shops, or used by electronics maintenance personnel during work on aircraft, as well as those normally classified as nonpowered handtools.

SAFETY, USE, AND CARE OF HANDTOOLS

Carelessness is the greatest menace in any shop. It must come from the man himself; the machine alone cannot inflict injury. Lack of care is the cause of most accidents in electrical and electronics shops today. It should be remembered that all moving machinery is potentially dangerous. It is unsafe to lean against any machine that is in motion, or that may be started in motion by anyone else. Treat a machine with businesslike respect and there is no need to fear it. Do not start a machine until its operation and safety precautions have been fully explained by a competent instructor.

Chapter 2 of this manual contains some information concerning safety precautions and practices involving machinery and tools; that material should be reviewed frequently. Other excellent sources of information regarding handtools and their use and care are Airman, NavPers 10307-C, and Basic Handtools, NavPers 10085-A. Since these manuals are basic to all aviation ratings, the material covered in them is not duplicated in this discussion; review of that material should be accomplished before proceeding with this manual.

The following two basic safety precautions may be used to summarize this idea, and they cannot be emphasized too strongly:

1. Use the proper tool for its own designed function, and use it in the proper manner.
2. Maintain all tools in proper working order and in a safe condition. Sharpen or replace dulled cutting tools, replace broken or defective tools, and protect tools from damage while in use or in storage.

When performing any function requiring the use of tools and/or materials, arrange them so that they are easily accessible but are not in a position to interfere with the work. This arrangement increases efficiency as well as safety.

Tools should be inventoried, cleaned, and inspected after the job has been completed. Return all tools to their proper storage place.

GENERAL TOOLS

Although the previously mentioned basic manuals provide many details regarding the common general tools, a few additional comments are of importance to the avionics maintenance technician.

Never use a center punch on extremely hard metals or to remove bolts by force; to do so will dull the point. Never use a pin punch as a starting punch—a hard blow may cause the slim shank to break. Always use the largest starting and pin punch that will fit the hole. When using punches, do not strike a glancing blow; the punch may break, and broken pin punches are difficult to remove.

Do not hammer on a screwdriver. If an obstruction is in the slot, apply a driving force with the heel of the hand or remove the obstruction with a file. Never use a screwdriver as a pry bar, lever, or chisel. Do not use pliers or wrenches on a screwdriver to increase torque.

When using a grinding wheel, insure that the guard is in place. If it is necessary to use the wheel with the guard removed, stand to one side to avoid flying particles of emery or metal. Use safety goggles when using a grinding wheel to grind screwdriver blades or any metal object. Use the rest stand when possible, but insure that the rest is close to the grinding wheel.

When drilling, never use the hand to hold the work being drilled. Use a vise or a clamp. The same idea applies to work being soldered, filed, or sawed.

Using a Reed and Prince screwdriver when working on Phillips screws (or vice versa) can result in a ruined tool. Also, using the wrong screwdriver may round out the screwhead, making it difficult to remove the screw. Because of the difference in design of the two screws, the screwdrivers should not be used interchangeably. In general, Reed and Prince screws are used for airframe structural applications, while Phillips screws are found most often in component assemblies.

Figure 3-1 shows the differences between types. The Phillips screwdriver has about 30-degree flukes and a blunt end, while the Reed and Prince has 45-degree flukes and a sharper, pointed end. The Phillips screw has beveled walls between the slots; the Reed and Prince, straight, pointed walls. In addition, the Phillips screw is not as deep as the Reed and Prince.

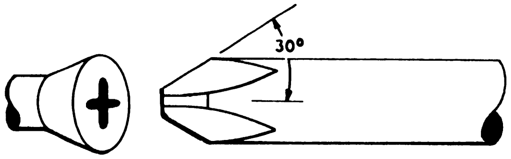
Ways to identify the right screwdriver are as follows:

1. If it tends to stand up unassisted when the point is put in the head of a vertical screw, it is probably the proper one.
2. The outline of the end of a Reed and Prince screwdriver is approximately a right angle, as seen in the illustration.
3. The best thing is to know the descriptions of both types.

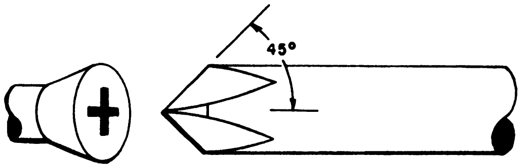
Using the right tool saves time and trouble, and is good maintenance practice.

SPECIAL TOOLS

Avionics maintenance technicians use many tools which are not covered in the basic manuals previously mentioned. A wide variety of special tools are furnished by the manufacturers of the aircraft, engines, and related equipment. These tools are listed in special allowance lists and their use is explained in the Maintenance or Service Instructions Manuals covering the specific aircraft, engine, or item of equipment for which they were designed. Other tools are peculiar to the maintenance of electronic equipments, or have been developed since the basic manuals have been issued.



(A) PHILLIPS



(B) REED AND PRINCE

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Figure 3-1.—Matching cross-slot screws and drivers.

Although the following list is not complete, it is representative of the special tools most commonly used in aircraft electronics maintenance work.

NONMAGNETIC TOOLS

Tools made of nonmagnetic materials are available through normal supply channels. They are used for performing specific maintenance functions on certain classes of equipment or components. These expensive tools are normally made of beryllium-copper or plastic, are not as rugged as steel tools, and are much more easily damaged. Restricting their use to the purpose for which they were intended will prolong their useful life and increase their usefulness when required.

In addition to possible damage of the tool itself, indiscriminate use of these tools could allow them to transfer foreign particles to locations where possible trouble could result.

Nonmagnetic tools should always be used in the vicinity of magnetrons and other components containing permanent magnets. Magnetic tools could be attracted with sufficient force to cause damage to the magnetic or injury to the technician; or the tool could become magnetized and transfer this magnetic condition to undesirable places.

Nonmagnetic tools should also be used in tuning RF circuits which are susceptible to frequency change resulting from the introduction of new magnetic fields (or the distortion of the existing magnetic fields). Many slug-tuned IF circuits involve this potential trouble.

Good general maintenance practice involves wiping the tools before use and again after use. This is especially advisable in the case of nonmagnetic tools. A lint-free cloth dampened with a suitable cleaning solvent may be used for this purpose.

INSULATED TOOLS

Safety considerations required use of insulated tools whenever the danger of electrical shock or short circuit exists. Many types of tools are available in insulated form directly through supply channels at little or no additional cost. These tools should be obtained and used whenever available. However, many types of insulated tools are not readily available (or are available only at considerable added expense). If essential, these tools should be procured or conventional tools may be modified. Insulated sleeving may be put on the handles of pliers and wrenches and on the shanks of screwdrivers. Tools modified in this manner should be used only for low voltage circuits because of the limitations of the insulating materials. For higher voltage uses, special insulating handles are available for many of the common types of tools.

In some instances, it is necessary to use tools which are made of insulating material, rather than merely having an insulating handle. In these instances, the tools should be requisitioned through normal supply channels, if possible. If they are not available through normal supply channels, they may be purchased on the open market.

TORQUE WRENCHES

There are times when, for engineering reasons, a definite pressure must be applied to a nut. In such cases a torque wrench must be used. The torque wrench is a precision tool consisting of a troque-indicating unit and appropriate adapter or attachments. It is used to measure the amount of turning or twisting force applied to a nut, bolt, or screw.

The three most commonly used torque wrenches are the deflecting beam, dial indicating, and micrometer setting types (fig. 3-2). When using the deflecting beam and the dial indicating torque wrenches, the torque is read visually on a dial or scale mounted on the handle of the wrench.

To use the micrometer setting type, unlock the grip and adjust the handle to the desired setting on the micrometer type scale, then relock the grip. Install the required socket or adapter to the square drive of the handle. Place the wrench assembly on the nut or bolt and pull in the desired direction with a smooth, steady motion. (A fast or jerky motion will result in an improperly torqued unit.) When the torque applied reaches the torque value which is indicated on the handle setting, the handle will automatically release or "break" and move freely for a short distance. The release and free travel is easily felt, so there is no doubt the torquing process is complete.

To assure getting the correct amount of torque on the fasteners, all torque handles must be tested at least once a month or more often if usage indicates it is necessary.

The following precautions should be observed when using torque wrenches:

1. Do not use the torque wrench as a hammer.
2. When using the micrometer setting type, do not move the setting handle below the lowest torque setting. However, it should be placed at its lowest setting prior to returning to storage.
3. Do not use the torque wrench to apply greater amounts of torque than its rated capacity.
4. Do not use the torque wrench to break loose bolts which have been previously tightened.
5. Never store a torque wrench in a toolbox or in an area where it may be damaged.

RELAY TOOLS

Many relays have been damaged or ruined by the use of sandpaper or emery cloth to clean the contact points. Use of these abrasives causes bending of the contacts, and attempts to

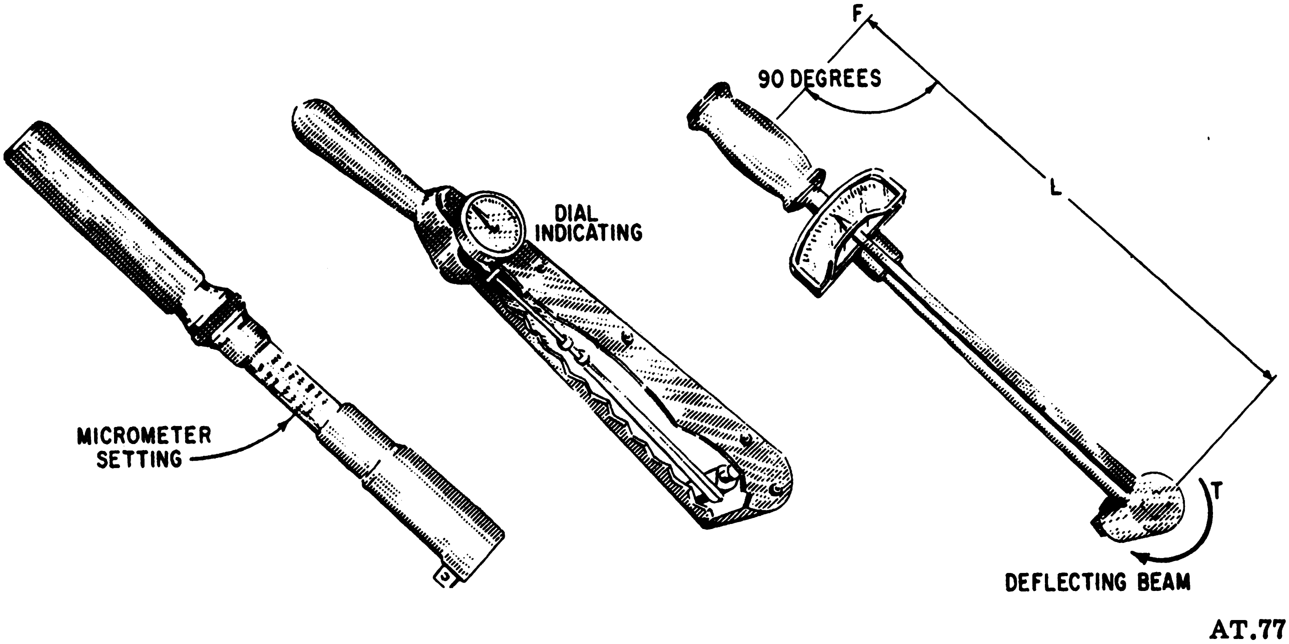


Figure 3-2.—Torque wrenches.

straighten them with longnose pliers cause further damage, eventually requiring replacement of the relays. This can be avoided by using a burnishing tool to clean dirty contact points. Figure 3-3 (A) illustrates a burnishing tool being used on a relay.

Burnishing tools are stocked in supply activities and may be obtained through normal supply channels. When using this tool, be sure to clean it thoroughly with alcohol; do not touch the tool surface with the fingers prior to use.

Burned and pitted contacts cannot be repaired by burnishing. Such relays should be replaced.

Another tool useful in relay maintenance is a point bender (fig. 3-3 (B)), which is used to straighten bent relay contacts. It can be fabricated locally from 0.125-inch diameter rod stock shaped as indicated in the figure.

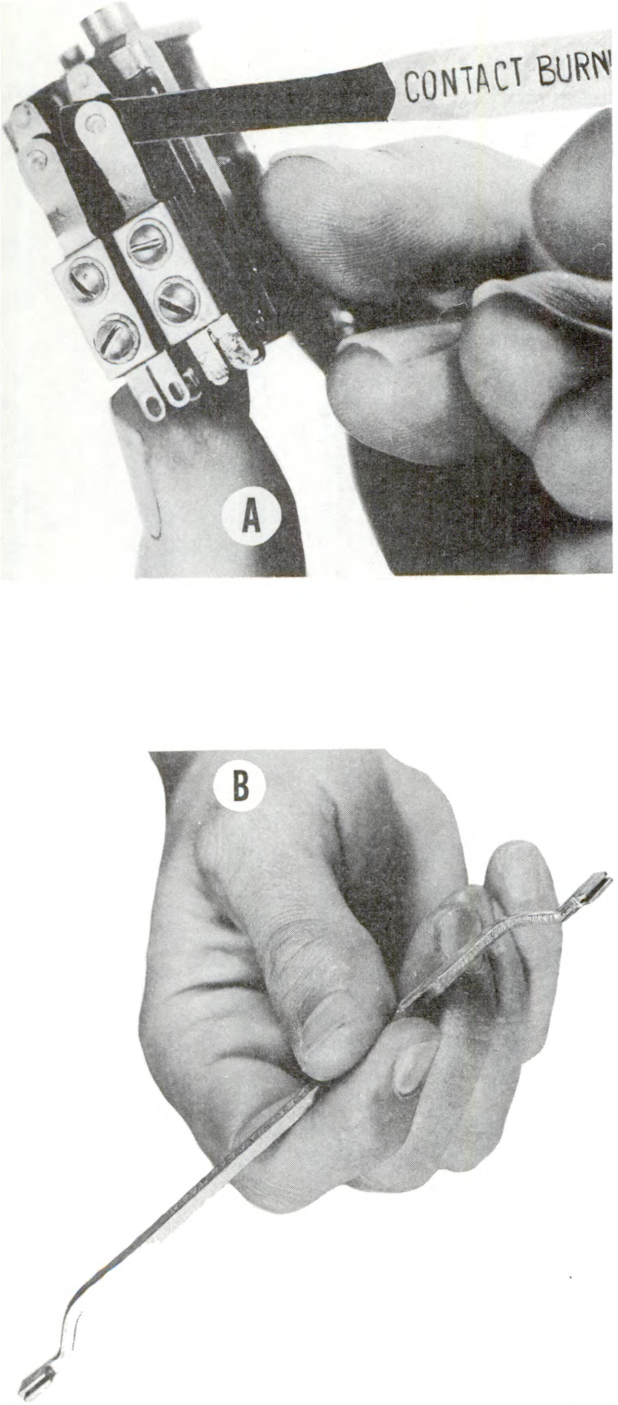
WIRE AND CABLE TOOLS

An innovation in electrical connectors is the taper pin electrical connector for aircraft. The taper pin works on the principle of driving a taper wedge into a tapered hole and depending on friction to retain the pin in the hole. The taper pin connector makes a very good electrical and mechanical connection because of the high metal to metal contact pressure developed during the driving action of the insertion tool. Taper pins permit circuit changes to be quickly and easily performed without a soldering iron. Tests show that vibration and corrosions, over a period of time, improve the electrical continuity and increase the mechanical pulling force required to remove a taper pin. Another advantage of taper pins is the accessibility of test points for voltage and circuit continuity checks.

Insertion and Removal

A special tool, shown in figure 3-4 is used to properly insert the taper pin into the terminal block socket. The insertion tool has a calibrated driving spring, a calibrated pull test spring, a taper pin captive key, and a taper pin removal feature.

The driving spring adjusts to apply the proper driving impact to the pin. The pull test spring adjusts to apply the correct pull force on the pin to check for proper pin insertion. The captive key insures that each taper pin has a 100 percent pull test before the tool is disengaged from the pin. The removal lever is rotated to remove the taper pin from the terminal block socket.



AE.35

Figure 3-3.—(A) Burnishing tool; (B) point bender.

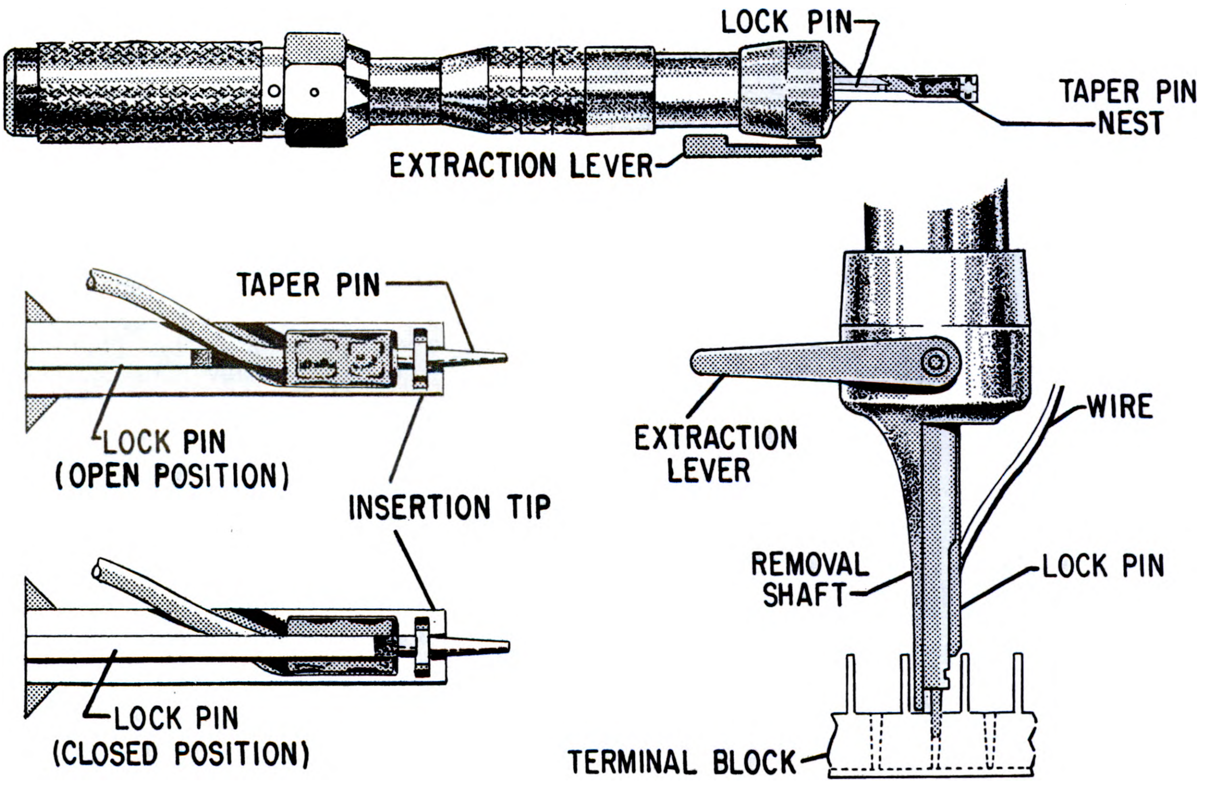
In order to maintain the reliability of the system, it is imperative that the taper pin be properly inserted into the terminal block sockets. Pushing the pins into the sockets with the fingers or pliers will not make them stay—they must be driven in with the insertion tool. The tool must be calibrated to insure that the proper pressures are used. When inserting the taper pins, the insertion tool must be held at right angles to the terminal block, and pushed straight toward the terminal block without twisting the tool. The pins are very sensitive to twists, which could cause a faulty connection or a broken pin. Bent or broken pins should always be replaced. However, if correct installation procedures are followed, a taper pin may be installed and removed as many as 25 times before replacement is necessary. A properly installed taper pin will pass the pull test of the insertion tool.

Three different sizes of taper pins are used to terminate wires from sizes 16 through size 22. The sizes are identified by color coding of the insulating sleeves. A crimping tool is used to attach the taper pin to the wire. This taper pin crimping tool is similar to other types of wire terminal crimping tools, such as those discussed later in this chapter.

DIAGONAL PLIERS

Diagonal pliers are described briefly in Basic Handtools, NavPers 10085-A. The following discussion describes a modification which is advantageous when the diagonal pliers are used in the maintenance of equipment aboard aircraft where working clearances are likely to be close.

The diagonal pliers (fig. 3-5) have been modified by adding potting compound to the jaws. This prevents loss of small pieces of wire into the equipment when cutting wire. The potting compound also allows the technician to cut the wire without holding onto the piece being cut away. (Figure 3-5 (A) shows the diagonals before being modified.) If you do not have a pair of these modified diagonal pliers, manufacture your own by adding potting compound. Before applying the potting compound, clean the diagonals with solvent; then secure the handles with a rubberband (fig. 3-5 (C)) and apply the compound. Allow 24 hours for the compound to dry. The jaws may be separated by slicing them apart with a single edge razor blade.



AE.36

Figure 3-4.—Taper pin insertion and removal tool.

SAFETY WIRING PLIERS

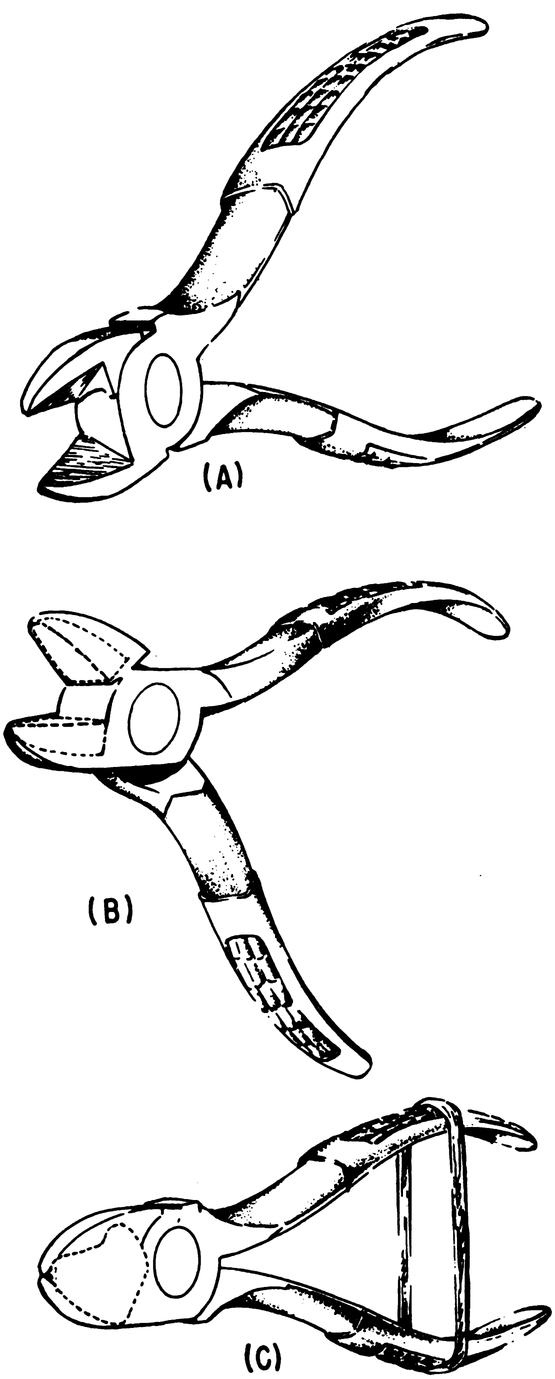
When installing equipment in aircraft, it becomes necessary to lockwire (usually referred to as safety wire) designated parts of the installation. The process of lockwiring can be accomplished faster and neater with the use of special pliers. However, the use of these pliers requires extreme care. The wire must be installed snugly, but not so tight that the part of the wire is overstressed. The routing of the twisted wire is prescribed by the particular installation, and in many instances is designated in the appropriate Maintenance Instructions Manual.

Safety wiring pliers (fig. 3-6) are three-way pliers, which hold, twist, and cut. They are designed to reduce the time used in twisting safety wire on nuts and bolts. To operate, grasp the wire between the two diagonal jaws, and the thumb will bring the locking sleeve into place. A pull on the knob twirls the twister, making uniform twists in the wire. The spiral rod may be pushed back into the twister without unlocking it, and another pull on the knob will give a tighter twist to the wire. A squeeze on the handle unlocks the twister, and the wire can be cut to the desired length with the side cutter. The spiral of the twister should be lubricated occasionally.

WIRE AND CABLE STRIPPERS

Nearly all wire and cable used as electrical conductors are covered with some type of insulation. In order to make electrical connections with the wire, a part of this insulation must be removed, leaving the end of the wire bare. To facilitiate the removal of this insulation, use a wire and cable stripping tool similar to the one shown in figure 3-7.

Although several variations of this basic tool are available, the most efficient and effective is the type illustrated. Its operation is extremely simple—insert the end of the wire in



AT.80

Figure 3-5.—Diagonal pliers. (A) without compound; (B) with compound; (C) apply compound.

the proper direction to the depth to be stripped, position the wire so that it rests in the proper groove for that size wire, and squeeze. The tool functions in three steps as follows:

1. The cable gripping jaws close, clamping the insulated wire firmly in place. The wire must be inserted so that the jaws clamp the main section of the wire rather than the end to be stripped.

2. The insulation cutting jaws close, cutting the insulation. If the wire is not inserted in a groove, the conductor will also be cut. If the wire is positioned into too small a groove, some of the strands will be severed. If the groove is too large, the insulation will not be completely severed. Inserted properly into the correct groove, the insulation will be cut neatly and completely, and the wire will not be damaged.

3. The two sets of jaws separate, removing the clipped insulation from the end of the wire.

If cable and wire strippers of this type are not available, notches may be cut in the jaws of diagonal pliers or pocket fingernail clippers, using jeweler's files. Care must be taken to file the grooves into the proper positions in opposing jaws, and the size of the groove must be appropriate for the size wire on which it is to be used. When properly modified, these tools will perform satisfactorily if the more desirable stripper is not available.

CRIMPING TOOLS

Type MS 25037-1

The standard tool MS 25037-1, issued for crimping solderless terminals, is for use with standard insulated copper terminal lugs manufactured according to MS 25036. The standard tool employs a double jaw to hold the terminal lug or splice. One side of the jaw applies crimping action to fasten the terminal to the bare wire when the terminal is inserted, as shown at the left in figure 3-8. When the tool is used correctly, a deep crimp is placed in the B area of terminal lugs and splices, as shown in diagrams on the right of the figure. A shallow crimp is applied to the portion of the terminal or splice which extends over the insulation of the wire, as indicated by the A area in the diagrams. This clamping action is provided by a recessed portion in the other side of the divided jaw. A guard, which should be in the position shown when crimping terminals, aids in proper positioning of the terminal. However, the guard must be moved out of the way when the tool is used for crimping splices, and it may not always be replaced when it should be.

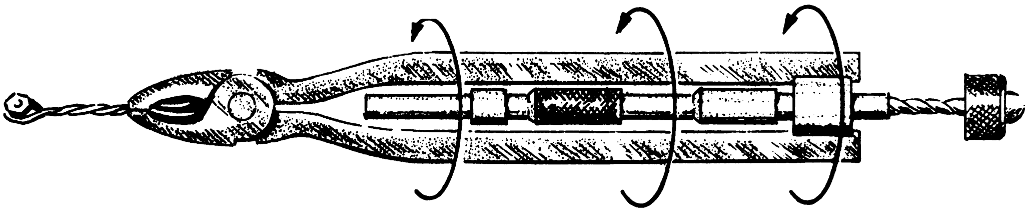


Figure 3-6.—Safety wiring pliers.

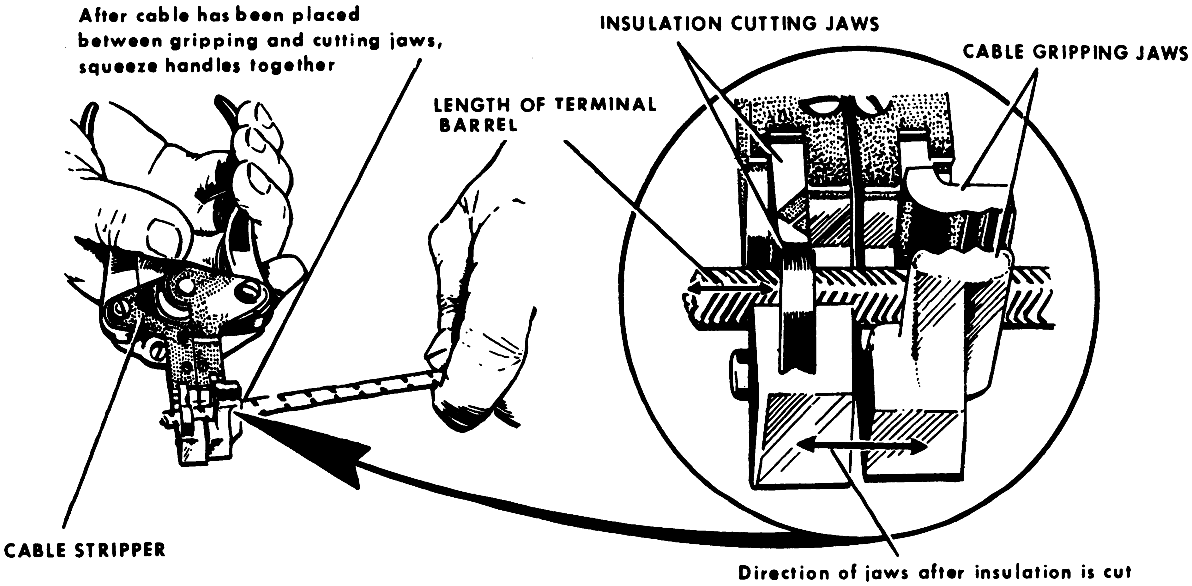

After cable has been placed between gripping and cutting jaws, squeeze handles together
INSULATION CUTTING JAWS
CABLE GRIPPING JAWS
LENGTH OF TERMINAL BARREL
CABLE STRIPPER
Direction of jaws after insulation is cut
AE.37

Figure 3-7.—Wire and cable stripper.

Without the guard, the tool may be used incorrectly; for example, the terminal might be inserted from the wrong side of the tool. The result is that the deep crimp is placed in the A area of the terminal or splice and, although the wire may be held securely in place, the connection is poor. Common sense indicates that the deep crimp must clamp the metal of the terminal to the bare metal of the wire in order to provide a good electrical and mechanical connection.

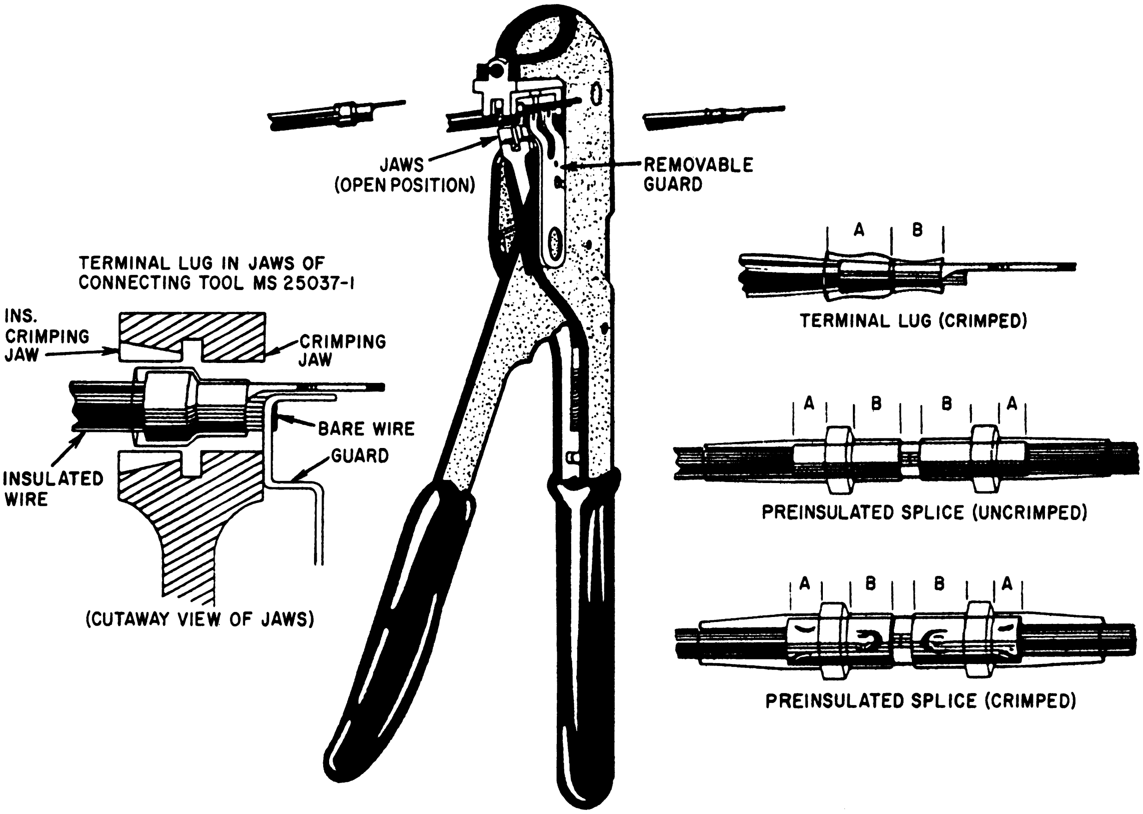
The MS 25037-1 tool requires occasional checking. A No. 36 (0.106) drill rod should not be able to enter the smaller (red or blue) nest when the tool is fully closed. If it does enter, have the tool repaired.

Instruction in proper crimping procedure should be furnished to all who need to make solderless terminal connections. Handbook of Installation Practices for Aircraft Electric and Electronic Wiring, NavAir 01-1A-505, contains detailed procedures for using many solderless connector tools.

Type MS 3191-3

This tool is the latest standard crimping tool designed specifically for use with type MS 3191 contacts for electrical connectors. It features interchangeable heads to accommodate various size terminals. It may be used with the turret (fig. 3-9 (A)) for normal use, or without the turret (fig. 3-9 (B)) for eyeball crimping.

Before using the tool, the correct selection must be made on the positioner head and also on the indentor gap selector plate. To release



AE.38

Figure 3-8.—Crimping tool MS 25037-1.

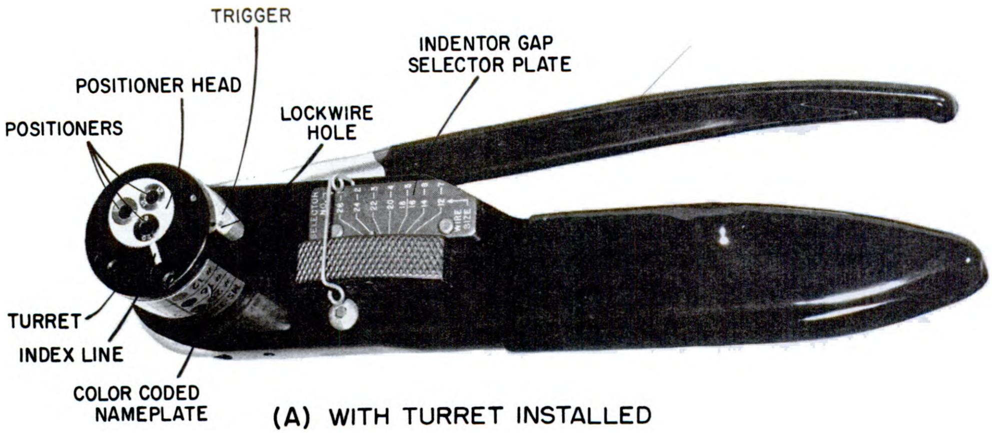
the turret for indexing, press the trigger and the spring-loaded turret snaps out to its indexing position. Select the desired position from the color-coded nameplate and rotate the turret to aline the selected positioner with the index. Depress the turret until flush, and the turret will automatically lock into place. To prevent further indexing, insert lockwire through the hole provided in the trigger.

To crimp a terminal, select the proper size and type terminal and insert the prepared wire into the contact pocket until the wire seats on the bottom. The wire should be visible through the inspection hole, and the insulation should enter the contact insulation support. Insert the contact and wire into the terminal crimping tool, making sure that the contact is properly seated in the positioner. Actuate the crimping tool handles to crimp the contact and wire. At the completion of the stroke, the ratchet releases; open the handles and remove the crimped contact from the tool.

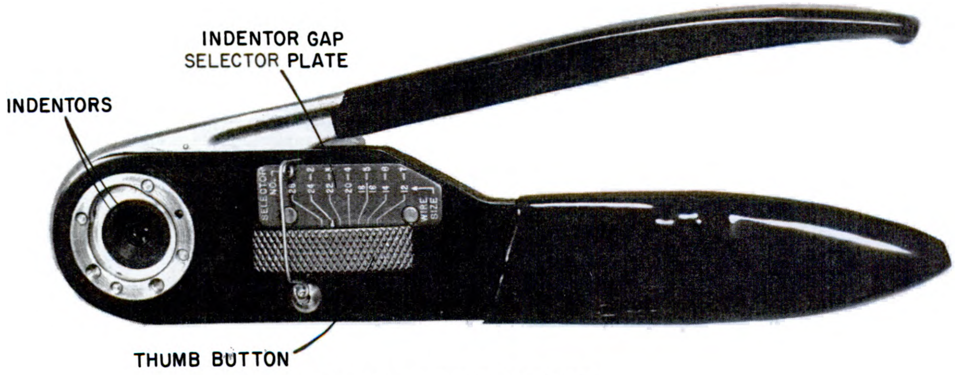
Inspect the crimped terminal and wire. The wire must be visible through the inspection hole. The insulation must be inside the insulation support. The crimping indents must be positioned between the inspection hole and the front of the insulation support. The contact must not be bent. The crimped contact is now ready to be installed into a connector.

For eyeball crimping, remove the head assembly from the tool. Select the proper wire size and move the thumb button until the pointer is alined with the selected wire size on the indentor gap selector plate. Holding the contact in the crimping tool, slowly close the handles, and at the same time position the contact so that the indentors are positioned midway on the contact barrel. Insert the wire, making sure it is bottomed in the contact, then close handles fully.

After releasing the handles, remove and inspect the crimped contact. The contact must not be fractured, and the conductor must be visible in the inspection hole.



(A) WITH TURRET INSTALLED



(B) WITH TURRET REMOVED

AE.39

Figure 3-9.—Crimping tool MS 3191-3.

SOLDERING GUNS, IRONS, AND TIPS

Soldering tools used in aviation maintenance activities come in many sizes and models. They may be of the gun type or of the common iron type. Irons come in a wide range of wattage ratings, and may operate on 28 volts d.c. or 115 volts a.c.

The iron most commonly used in avionics maintenance is the pencil type. (See fig. 3-10.) The use of this tool and its special tips is recommended in those instances when the applied heat must be kept to a minimum. These operations include all cases involving transistors, printed circuit repair, miniaturized components, etc.

Because of its rapid heating and cooling, the soldering gun has gained great popularity in recent years. It is especially well adapted to maintenance and troubleshooting work where only a small part of the technician's time is spent actually soldering. An iron continuously hot oxidizes rapidly and is difficult to keep clean.

A transformer in the gun supplies about 1 volt at high current to a loop of copper that serves as the tip. It heats to soldering temperature in 3 to 5 seconds, but will heat to as high as 1,000°F if left on longer than 30 seconds. Because it operates for short periods of time, very little oxidation is allowed to form; thus, it is one of the easiest soldering tools to keep well tinned. On the other hand, this tip is made of

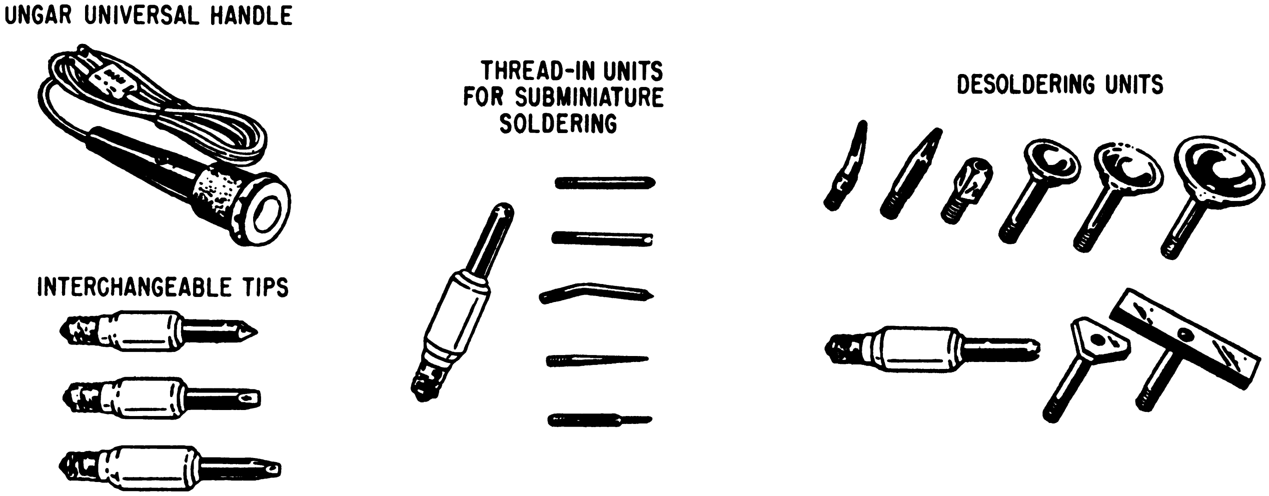


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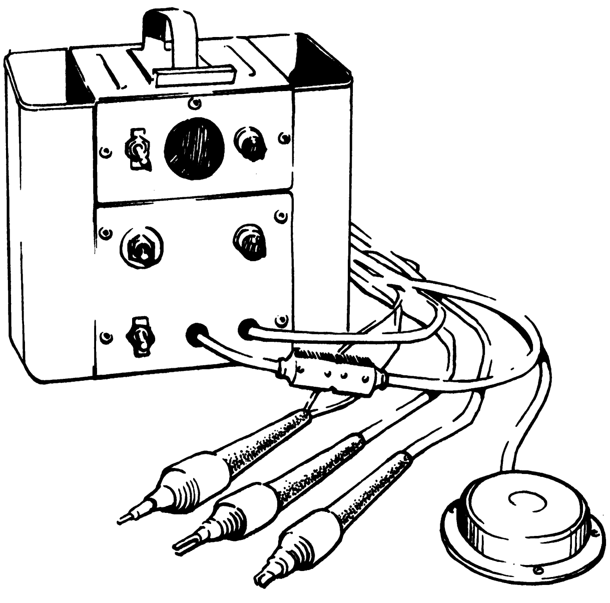
Figure 3-10.—Pencil iron with special tips.

pure copper with no plating, so pitting can easily occur as a result of the dissolving action of the solder. Offsetting this disadvantage, however, is the low cost of replacement tips.

To obtain best results from a soldering gun or iron, the tip must be kept free of oxide and scale. Most technicians wipe the tip on cloth, then file and retin as necessary.

A faster way is the "damp sponge" method. A dampened cellulose sponge is secured in a container such as a soapdish or metal ashtray. (The sponge is more effective than the cloth in keeping the tip clean, and presents no safety problems.) The damp sponge prevents the splattering that sometimes occurs when the heated tips are wiped off in the usual way, and also absorbs particles that may otherwise injure the technician's face. The sponge eliminates oxide and scale, so filing and retinning are kept to a minimum.



AE.46

Figure 3-11.—Resistance soldering unit.

Resistance Soldering Unit

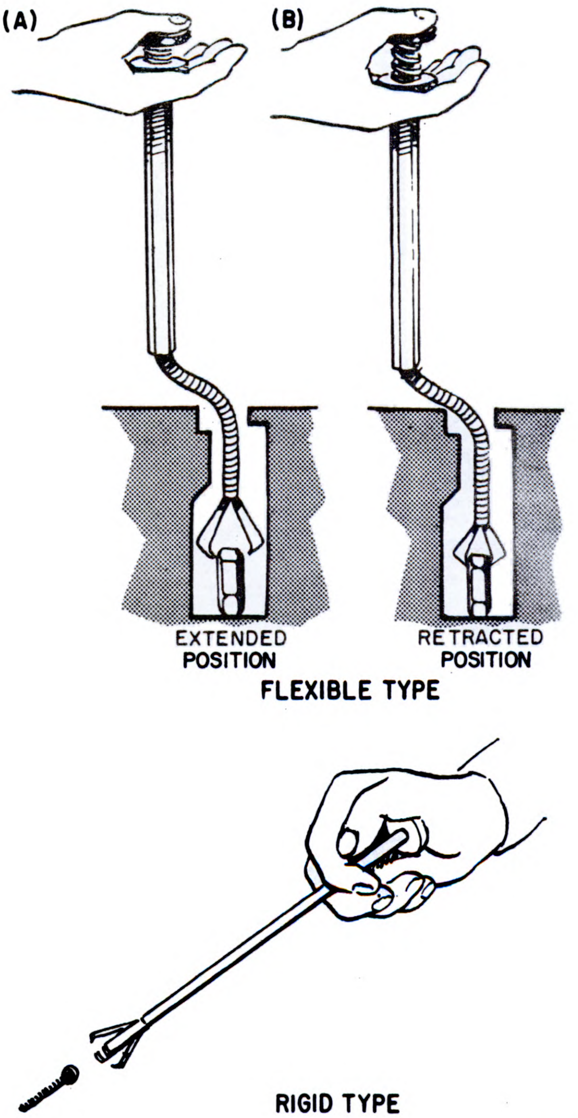
A time-controlled resistance soldering set (fig. 3-11) is available through normal supply channels. The set consists of a transformer that supplies 3 or 6 volts at high current to stainless steel or carbon tips. The transformer is turned ON by a foot switch and OFF by an electronic timer. The timer can be adjusted for as long as 3 seconds soldering time. This set is especially useful for soldering cables to AN plugs and similar connectors—even the smallest types.

In use, the double-tip probes of the soldering unit are adjusted to straddle the connector cup to be soldered. One pulse of current heats it for tinning and, after the wire is inserted, a second pulse of current completes the job. Since the soldering tips are hot only during the brief period of actual soldering, burning of the wire insulation and melting of connector inserts are greatly minimized.

MECHANICAL FINGERS

Small articles which have fallen into places where they cannot be reached by hand may be retrieved with the mechanical fingers. This tool is also used when starting nuts or bolts in difficult areas. The mechanical fingers (fig. 3-12) have a tube containing flat springs which extend from the end of the tube to form claw-like fingers, much like the screw holder. The springs are attached to a rod that extends from the outer end of the tube. A plate is attached to the end of the tube, and a similar plate to be pressed by the thumb is attached to the end of the rod. A coil spring placed around the rod between the two plates hold them apart and retracts the fingers into the tube. With the bottom plate grasped between the fingers and enough thumb pressure applied to the top plate to compress the spring, the tool fingers extend from the tube in a grasping position. When the thumb pressure is released, the tool fingers retract into the tube as far as the object they hold will allow. Thus, enough pressure is applied on the object to hold it securely. Some mechanical fingers have a flexible end on the tube to permit their use in close quarters or around obstructions.

NOTE: Mechanical fingers should not be used as a substitute for wrenches or pliers. The fingers are made of thin sheet metal and can be easily damaged by overloading.



AT.82

Figure 3-12.—Mechanical fingers.

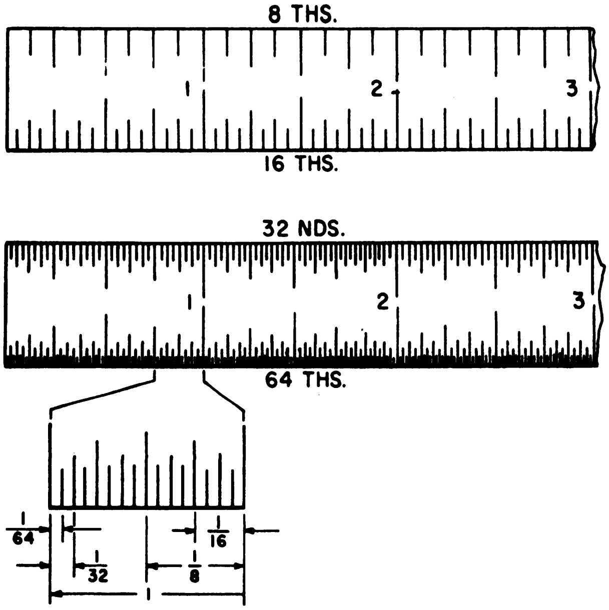
STEEL SCALE

The steel scale (fig. 3-13) is a measuring device that will usually be found in a toolbox. It is graduated in divisions of 1/8 and 1/16 inch on one side and 1/32 and 1/64 inch on the other side. The steel scale most commonly used is 12 inches long.

Measurements are taken with a steel scale by holding it on its edge on the surface of the subject being measured. This will prevent making errors which might be caused by the thickness of the scale. Such thickness causes the graduations to be a slight distance away from the surface of the object. Measurements are read at the graduation which coincides with the distance to be measured.

FLASHLIGHT

Each toolbox should have a standard Navy vaporproof two-cell flashlight. The flashlight is used constantly during all phases of maintenance. Installed in both ends of the flashlight are rubber seals which keep out all vapors.



AT.83
Figure 3-13.—Steel scale.

The flashlight should be inspected periodically for the installation of these seals, the spare bulb, and red lens which are contained in the end cap. NOTE: Do not throw away the red lens; it will be necessary during night operations.

INSPECTION MIRROR

There are several types of inspection mirrors available for use in aircraft maintenance. The mirror is issued in a variety of sizes and may be round or rectangular. The mirror is connected to the end of a rod and may be fixed or adjustable. (See fig. 3-14.)

The inspection mirror aids in making detailed inspection where the human eye cannot directly see the inspection area. By angling the mirror, and with the aid of a flashlight, it is possible to inspect most required areas.

CANNON PLUG PLIERS

Figure 3-15 displays a set of special pliers used to remove electrical connectors when they are on so tight that they cannot be removed by hand. These pliers when properly used will prevent damaging or destroying electrical connectors.

PRINTED CIRCUIT REPAIR TOOLS

A kit containing hand-held tools, microelement-handling units, and soldering materials, all selected because of their usefulness in repairing avionics modules, is known as an avionics module repair kit. This kit may be ordered through normal supply channels by any authorized maintenance activity. (The federal stock number is VX 4920-808-6663.) It consists of 61 items stored in the trays of a portable case. Figure 3-16 shows the upper tray of the carrying case, and figure 3-17 shows the arrangement at the bottom of the carrying case. The items are numbered in figures 3-16 and

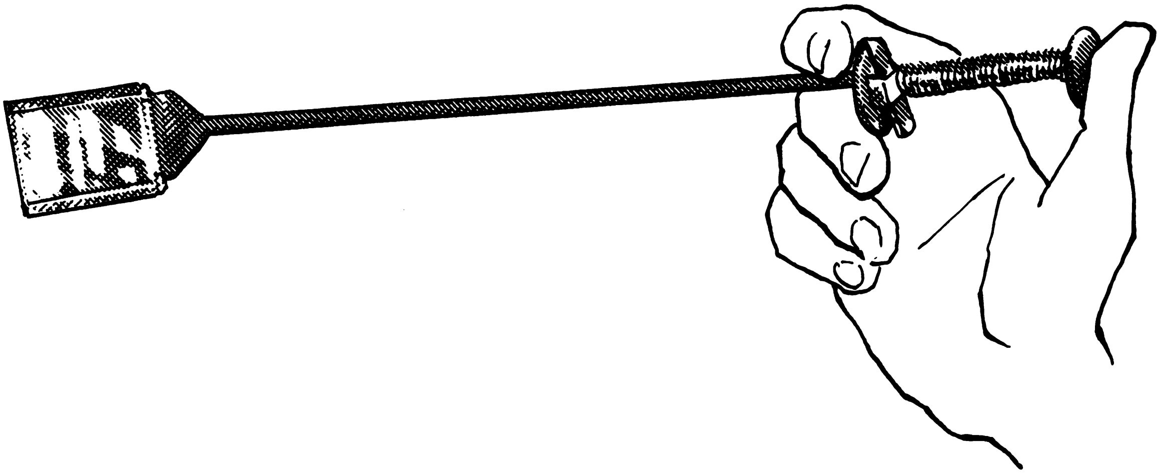


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Figure 3-14.—Typical inspection mirror.

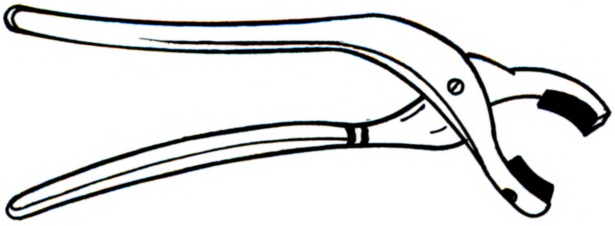

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Figure 3-15.—Cannon plug pliers.

3-17 to correspond with the numbers in table 3-1 which also lists the nomenclature of the items.

A brief description of most of the items in the kit is given below to help the technician realize how valuable this kit can be in repairing printed circuits.

Items 1-10 are used with the flexible drive shaft and handpiece assembly (items 37 and 38), which in turn are powered by the portable power pak (item 61) to do the necessary drilling, cutting, grinding, and polishing when components are removed. When these attachments are used, they should be operated at a uniform speed and applied with controlled pressure.

Item 11 contains tips for the solder extraction system, which is described later.

Item 12 is used with the small area spray system (item 41) and solvent (item 39) to clean any greasy residue from small areas to be repaired.

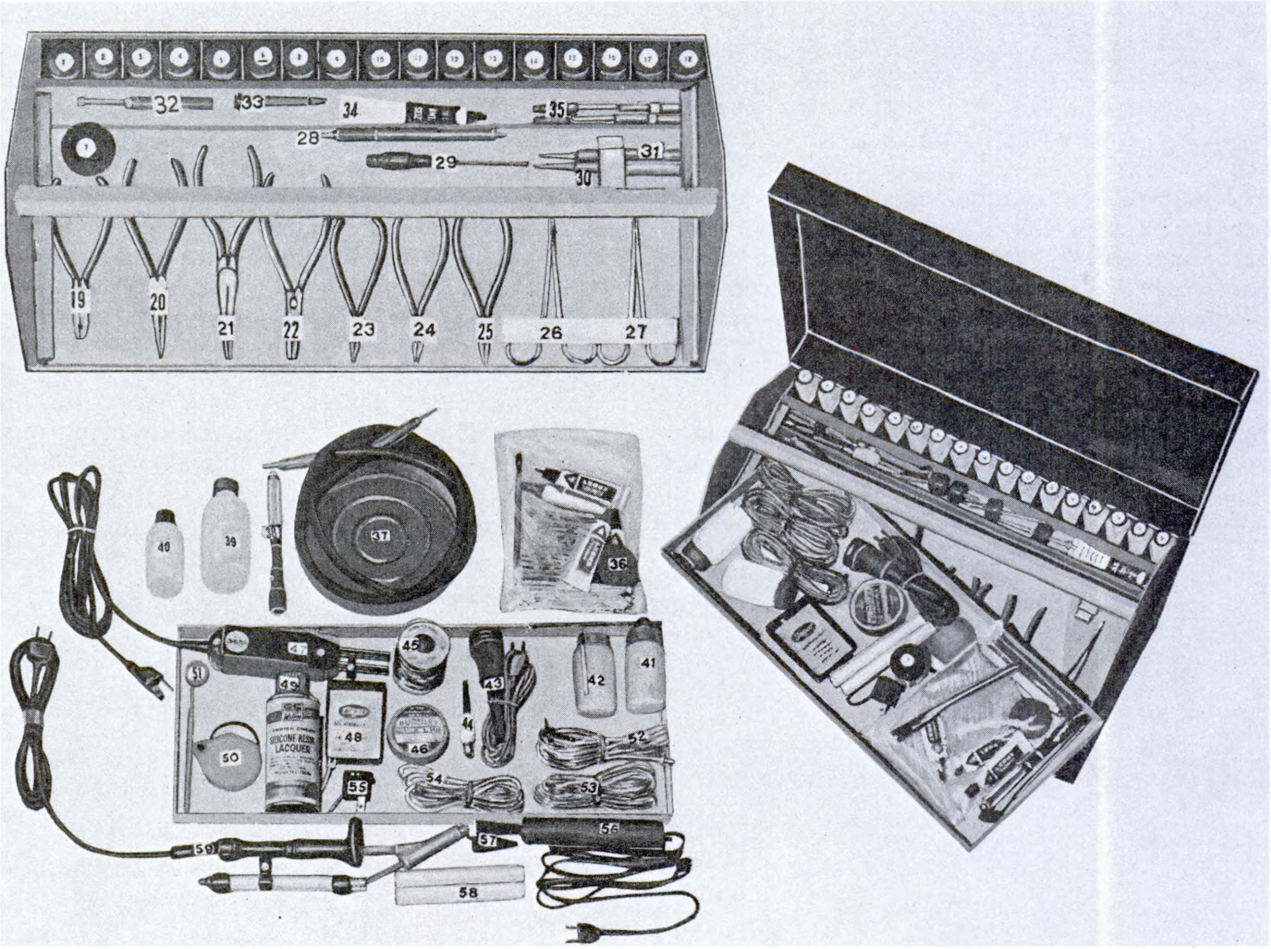

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Figure 3-16.—Upper trays of carrying case.

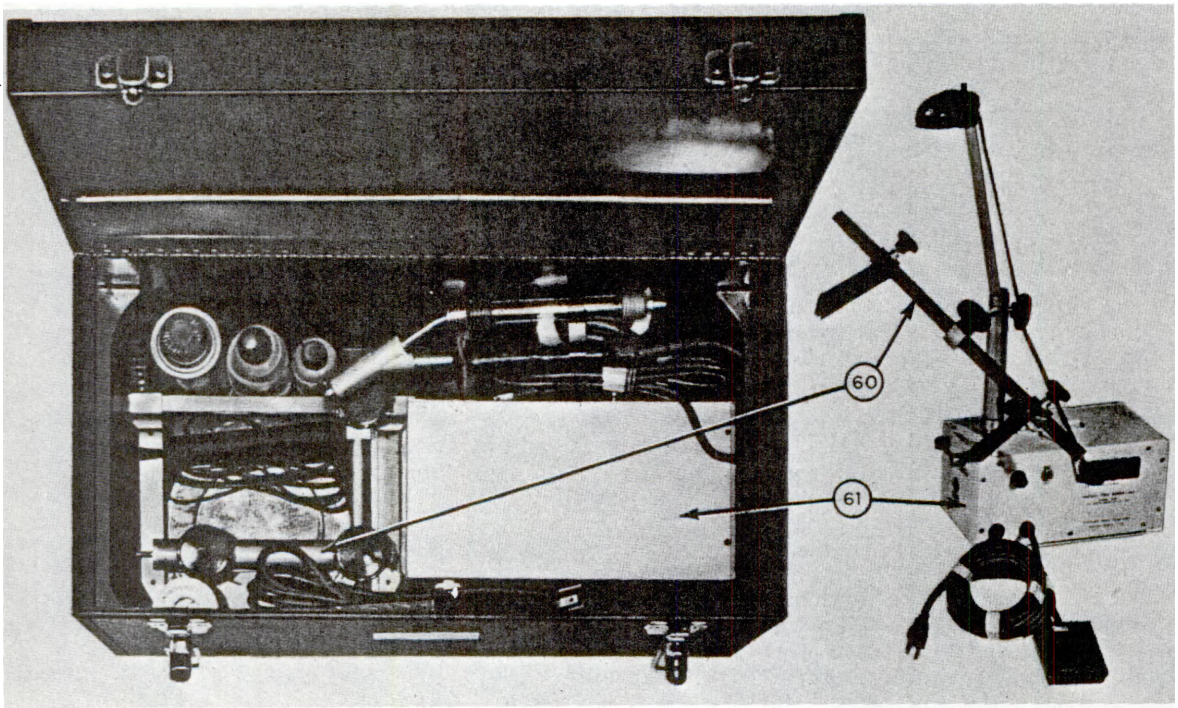

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Figure 3-17.—Storage arrangement at bottom of carrying case.

Item 13 contains blades for the thermal stripper, which is discussed later.

Item 14 contains tips for the vacuum tweezer, which is discussed later.

Items 15, 16, 17, and 33 are various wrenches and screwdrivers which, when used, should be used with moderate pressure to prevent breakage or damage to the printed circuits.

Items 18, 26, and 27 are heat sinks and clamps which are used to prevent damage to components by the dissipation of the heat required to desolder or solder.

Items 19-25 are various pliers used for bending leads, cutting wire, and general circuit work.

Items 14 and 28 comprise the vacuum tweezer and cleaning system. Item 28 is a cylindrical type vacuum probe that has no valve, but only a hole open to the atmosphere. The probe is connected to the vacuum source by means of the plastic hose assembly (item 52 and 53). The appropriate tip (item 14) is attached to the end of the probe closest to the finger hole.

The probe is designed to handle small parts and provides instantaneous and positive pickup and release of parts. Effective use of the probe can prevent damage to miniature parts, as it is capable of handling items as small as 0.0006 inch in diameter. It can also pick up ceramic and glass substrate, paper-thin elements, wafers, pellets, etc. The kit contains three probe tips.

The probe operates by activating the foot switch of item 61 to produce a vacuum and then covering the hole with a finger to extend the vacuum to the tip of the probe. To release an object, simply remove the finger from the hole. Complete vacuum cleaning of electronic components can be accomplished with brush type tips.

Item 34 is a high temperature lubricant which should be applied to soldering gun tips, stripper tip screws, and other areas in which heat may cause a threaded part to seize. It should be applied to the threaded part before the mating part is attached.

Item 37 is a flexible drive shaft driven by the power pak (item 61) and is used in conjunction with the handpiece (item 38) to drive the various drills, ball mills, slotting saws, and abrasive wheels.

Item 47, a thermal wire stripper (fig. 3-18), is a compact self-contained unit that uses no

Table 3-1.--Parts list of kit items.

Item No.	Description
1-vial #1	Mandrel, screw clamp
	Mandrel, screw thread
2-vial #2	Drills, inch
	.032
	.047
	.062
	.078
	.093
3-vial #3	Ball mills, inch
	.018
	.032
	.047
	.062
	.093
	.125
	.156
	.187
	.250
4-vial #4	Brass brush 3/16" dia.
	Fiber brush 3/16" dia.
	Spare fuse
5-vial #5	Slotting saw .088" dia.
	Abrasive wheel, fine, red, 5/8" dia.
	Abrasive wheel, coarse, green, 5/8" dia.
6-vial #6	Abrasive point .163" dia., white, soft material
	Abrasive point .163" dia., red, hard material
	Abrasive point .106" dia., conical, white, soft material
	Abrasive point, .106" dia., conical, red, hard material
	Abrasive wheel, silicon carbide, red, hard material, 7/16" dia.
7-vial #7	Abrasive wheel, tapered, red, 7/8" dia.
	Abrasive wheel, tapered, green, 7/8" dia.
8-vial #8	Bristle brush, 3/4" dia.
	Bristle brush, 5/8" dia.
9-vial #9	Fine abrasive point, red, 1/4" dia.
10-vial #10	Coarse abrasive point, green, 1/4" dia.
11-vial #11	Tips, solder-extraction system, inch
	.020
	.036
	.061
	.095
12-vial #12	Nozzle tips, spray system
13-vial #13	Blades, thermal stripping system
14-vial #14	Tips, vacuum tweezer, straight with .060 ID, 45 degrees
	Tips, vacuum tweezer, angled with .060 ID
	Tips, vacuum tweezer, angled with .050 ID with soft brush at tip
15-vial #15	Allen wrench set #4, #6 & #8; Phillips screwdriver set size #0 & #1
16-vial #16	Flat screwdriver: awl set blade sizes .055, .070, .080, .100; awl size .10
17-vial #17	Socket wrench set 5/64, 3/32, 7/64, 1/8 and 5/32
	Open end wrench set 5/64, 3/32, 7/64, 1/8 and 5/32
18-vial #18	Miniature heat sinks
19	Diagonal cutting pliers 4 1/2"
20	Longhose pliers 6" CM55
21	Extra-fine needlenose pliers 6"
22	Side-tip nose cutting pliers 6"
23	Short-chain nose pliers 5"
24	Flatnose plier 4 1/2"
25	Roundnose pliers 5"

Table 3-1.--Parts list of kit items--Continued.

Item No.	Description
26	Straight heat-sink clamp
27	Curved heat-sink clamp
28	Vacuum tweezer and cleaning system
29	Utility screwdriver
30	Tweezer, serrated, nonmagnetic stainless
31	Tweezer, smooth, nonmagnetic stainless
32	Fiberglass brush
33	Handle to fit tool sets contained in vials 15, 16, 17
34	High-temperature lubricant
35	Oxide remover
36	Epoxy kit consisting of: (a) Wood spatula (b) Work platen (c) Brush (d) Mixing cup (e) Epoxy-resin cement
37	48" flexible drive shaft
38	#8 handpiece
39	4-ounce trichloroethane solvent
40	2-ounce stripvar
41	Small-area spray system
42	2-ounce bottle nalgene with #2104, 2 1/4" tube
43	Pencil soldering iron
44	Tip for pencil soldering iron
45	Energized rosin-cored solder 60/40 .032" dia.
46	Soldering paste--2-ounce
47	Thermal stripping
48	Cleaning unit
49	6-ounce silicone coating
50	2-power magnifying lens
51	Mirror extended 45 degrees
52	Hose assy, flexible plastic hose, 5' with 1 De Vilbiss #630 TA cutoff and 1 Hansen B-1-T125 fitting
53	Hose assy, clear plastic tubing, 5' with 1 Hansen B-1-T125 fitting
54	Hose assy, clear plastic tubing, 5' with 1 Hansen B-1-T125 fitting
55	Polarized plug
56	Heat probe system
57	Heat probe, directional cones
58	Spare reservoirs for solder-extraction system
59	Solder extraction system
60	Illuminated work-holding-and-positioning unit
61	Portable power pak

external transformers or power supplies. Its steel-alloy heated blades (item 13) are mounted on electrodes protruding from the front of the unit. The upper-blade-and-electrode assembly is mounted on a movable arm, which is operated by the thumb to apply pressure to close the jaws, and contains a small red button that is depressed to heat the blades.

As shipped from the factory, the blades are notched to receive AWG 24 or larger wire. To meet exacting stripping requirements, the notch should be slightly larger than the diameter of the wire to be stripped. The tool can be used with wire as small as AWG 43. For wire smaller than AWG 32, however, unnotched blades should be used. Additional blades, which may

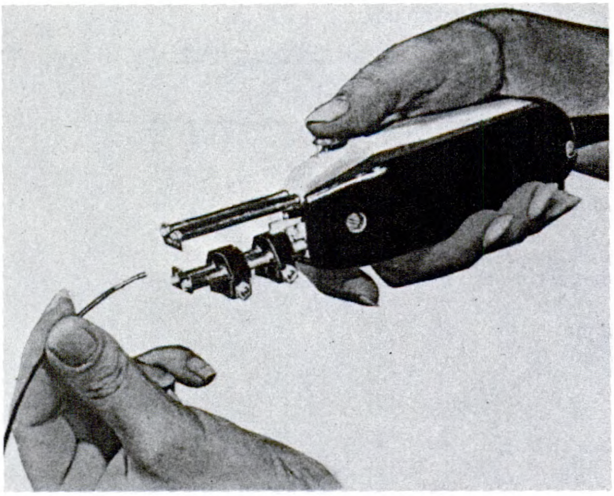

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Figure 3-18.—Thermal wire strippler.

be obtained directly from the manufacturer, are left unnotched so that the user may notch them to his own requirements. Notched blades for any size of wire may be obtained on special order from the manufacturer.

CAUTION: Teflon, PVC, and silicone-rubber insulations should be stripped in a well-ventilated area because in the process a small amount of toxic gas may be emitted.

After considerable use, the stripper blades will become encrusted with residue from the wire coverings. Sometimes this residue can be burned off by the application of full heat to the blades for a minute. If heat does not burn off the residue, the residue can be easily removed with a soft wire brush without damage to the blades.

When installing new blades, carefully check the alinement of the notches and be certain that the retaining screws are tightened.

CAUTION: The stripper will not function or heat properly unless the retaining screws holding the blades are tightened as firmly as possible.

Item 59 is the solder extraction system; an example of its use is shown in figure 3-19. It is connected to the power pak (61) by a clear plastic hose contained in the kit. The vacuum outlet then sucks away the solder as it is melted with the iron. The solder extractor has a large area of heat radiation, so the person using it should be aware of its workbench placement to prevent possible burn injuries and equipment damage.

Item 60 is an illuminated work-holding-and-positioning unit (fig. 3-17) and is used to hold and position circuit boards or modules. Since the light above the unit is usually insufficient, additional light may have to be provided. When this unit is holding assemblies other than circuit boards, it will be necessary to attach the chassis holders (item 35) or modular holders (item 34) to the top of the movable board-holder bars.

Item 61, the portable power pak, supplies compressed air and vacuum for using the solder extraction system, heat probe, vacuum tweezer, and spray unit and has a mechanical drive chuck for the turning of the flexible drive shaft handpiece assembly (items 37 and 38) during drilling, grinding, and polishing operations. In addition, the pak has three 110-volt a-c electrical outlets that furnish required power for the various tools. Foot operation of the power pak—to obtain compressed air, vacuum, or power—is controlled by a microswitch. However, the application of more or less pressure to the foot switch does not permit control of speed.

TOOL KITS, SHOP TOOLS, AND TOOL CRIBS

One of the first steps taken when a new man reports for duty to the avionics shop of a squadron or activity is to issue him an individual toolbox. The toolbox should contain the low-cost, high-usage handtools that will enable him to perform the tasks assigned. The purpose of the individual handtool kit is to make the necessary tools for performance of line and/or hangar maintenance immediately available to the individual. The contents of the individual handtool kit are among the tools listed in Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NavAir 00-35QG-016.

Under the crew leader concept of maintenance, the crew leader's kit has the same type tools as the individual handtool kit. It is issued to an individual of a crew and is to be used by all members of that crew. Thus, the crew leader's handtool kit will have several of the same type and/or size tool where the individual kit has only one.

Shop tools are the larger, low-usage, and special tools for use on specific equipments. A shop tool bin is normally utilized to make available to the technician those special tools and medium-usage tools needed to perform the various phases of shop maintenance. However, shop tools also include any handtools required

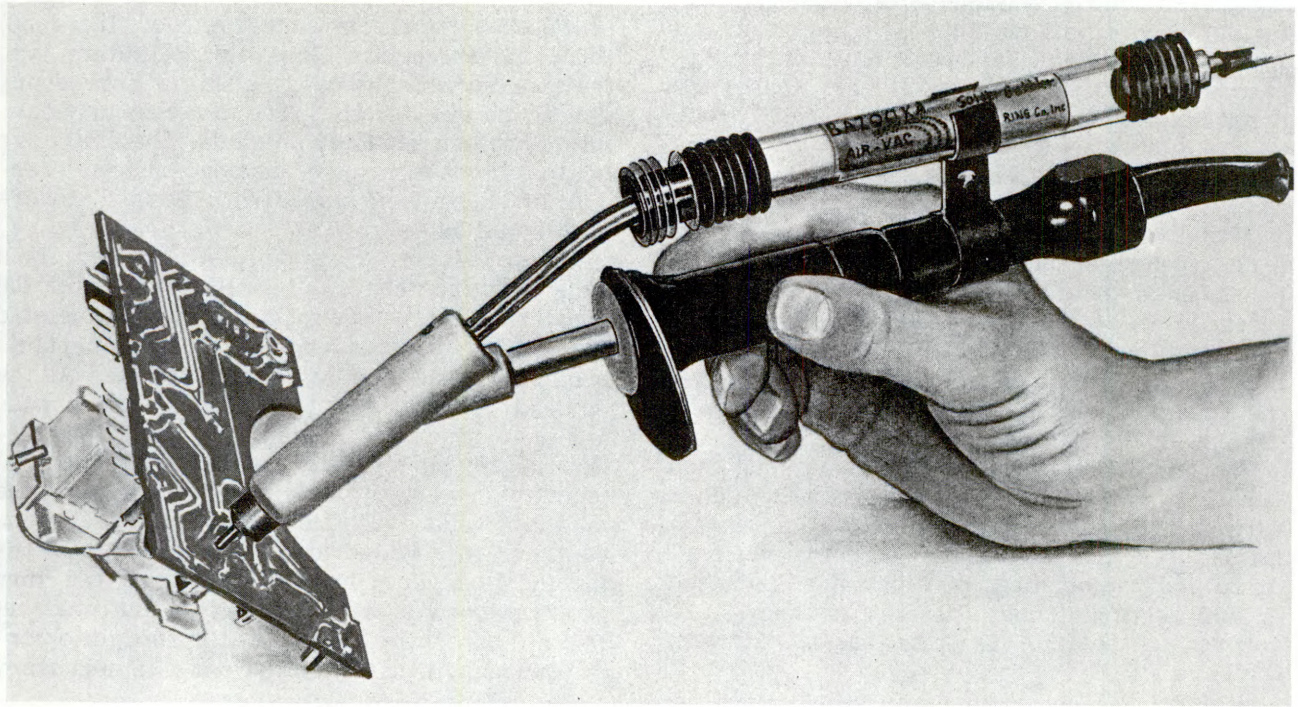

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Figure 3-19.—Solder extraction tool.

to perform more extensive maintenance than can be accomplished from a toolbox or a crew leader's kit. To determine the types and number of shop tools allowed, refer to the applicable allowance list from the NavAir 00-35QG-0 series.

Frequently a squadron toolcrib has the responsibility for all tools in the squadron, including issuance of tools, inventory of toolboxes, and ordering new tools for replacement of broken or lost tools. A squadron toolcrib is set up under the responsibility of the maintenance department. Its purpose is for the stowage and issuance of low-usage handtools and those which are common to more than one shop. Special tools provided by the aircraft manufacturer are also stowed in the toolcrib. A complete list of these special tools can be found in the Maintenance Instructions Manual, section one, for each type aircraft.

The tools used in an aircraft maintenance activity are determined by the mission of the activity and the type aircraft to be maintained. In view of this, there is no hard and fast rule as to the type and/or number of tools that may be supplied in the different handtool kits and cribs. The quantity and types of tools allowed for an activity may be found in the appropriate allowance list.

AIRCRAFT HARDWARE AND CONSUMABLE MATERIALS

MOUNTING PARTS

Items of hardware used when installing equipment in aircraft are specified in the applicable Maintenance Instructions Manual. In all instances, the proper parts should be used; if substitution becomes necessary, care must be taken that the substitute item is satisfactory in all respects.

It is not always desirable to use the same mounting parts that were removed from the installation. Prior to reinstalling the same items, an inspection must be made to insure that the parts are of the type specified, and are not defective or damaged. It must also be determined that instructions do not forbid their reuse. Then, and only then, may the removed parts be reinstalled.

General information regarding such mounting parts as screws, nuts, bolts, washers, etc., is included in various Rate Training Manuals. Aircraft Structural Hardware for Aircraft Repair, NavAir 01-1A-8, is a valuable source for detailed information.

TURNLOCK FASTENERS

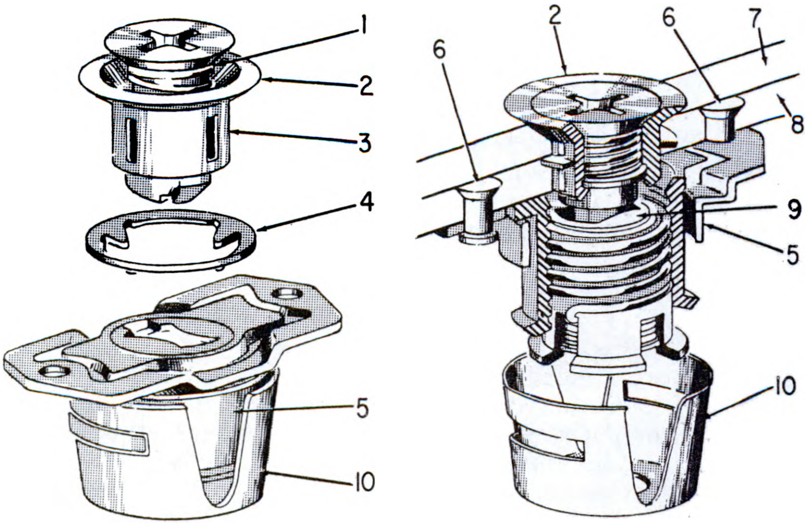
Turnlock fasteners are used to secure inspection plates, doors, and other removable panels on aircraft. Turnlock fasteners are also referred to by such terms as quick-opening, quick-action, and stress panel fasteners. The most desirable feature of these fasteners is that they permit quick and easy removal of access panels for inspection and servicing purposes.

Turnlock fasteners are manufactured and supplied by a number of manufacturers under various trade names. Some of the most commonly used are the Camloc stress panel fastener and Airloc, both of which are discussed in this section. Other turnlock fasteners are covered in the Rate Training Manual Airman, NavPers 10307-C.

Camloc Stress Panel Fasteners

The Camloc stress panel fastener (fig. 3-20) is a high-strength, quick-release, rotary type fastener and may be used on flat or curved, inside or outside panels. The fastener may have either a flush or nonflush stud. The studs are held in the panel with flat or cone-shaped washers, the latter being used with flush fasteners in dimpled holes.

This fastener may be distinguished from screws by the deep No. 2 Phillips recess in the stud head and by the bushing in which the stud is installed. A threaded insert in the receptacle provides an adjustable locking device. As the stud is inserted and turned counterclockwise 1/2 turn or more, it screws out the insert sufficiently to permit the stud key to engage the insert cam when turned clockwise. Rotating the stud clockwise 1/4 turn engages the insert; and continued rotation screws the insert in, tightening the fastener. Turning the study 1/4 turn counterclockwise will then release the stud but will not screw the insert out far enough to permit reengagement in installation. It is necessary



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1. Tension spring.
2. Stud assembly.
3. Bushing.
4. Retaining ring.
5. Receptacle assembly.
6. Receptacle attaching rivets.
7. Outer skin.
8. Inner skin.
9. Insert
10. Cover.

Figure 3-20.—Camloc stress-panel fastener.

to turn the stud at least 1/2 turn counterclockwise to reset the insert.

To unlock the stress-panel fastener and reset it in the same operation, use a No. 2 Phillips screwdriver, turning the stud counterclockwise 1/2 turn or more. Do not turn the stud past stop.

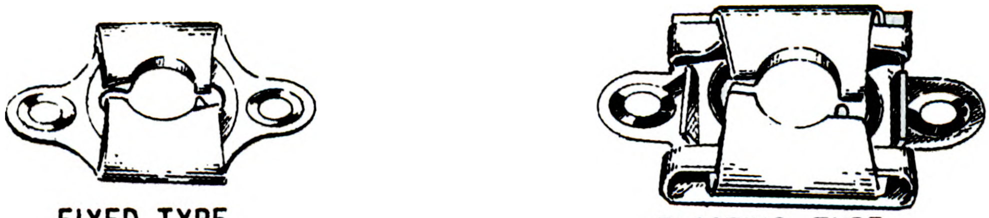
CAUTION: Do not use a power screwdriver on this fastener.

To lock, use a Phillips No. 2 screwdriver, push the stud in, and turn clockwise until increased torque is felt; then continue turning until the fastener is tight.

NOTE: When installing a large panel, it may be necessary to engage all the fasteners before tightening. This is done by pushing each stud in and turning it clockwise 1/4 turn. The stud should engage the receptacle but remain loose. If the stud does not engage, it will pop out, indicating that the insert must be reset by turning the stud counterclockwise 1/2 turn or more.

Airloc Fastener

The Airloc fastener consists of a stud, stud cross pin, and a receptacle. (See fig. 3-21.) The stud is attached to the access cover, and is held in place by the cross pin. The receptacle is riveted to the access cover frame. A quarter turn of the stud (clockwise) locks the fastener in place; turning the stud counterclockwise, unlocks the fastener.



FIXED TYPE
(A)

FLOATING TYPE
(B)

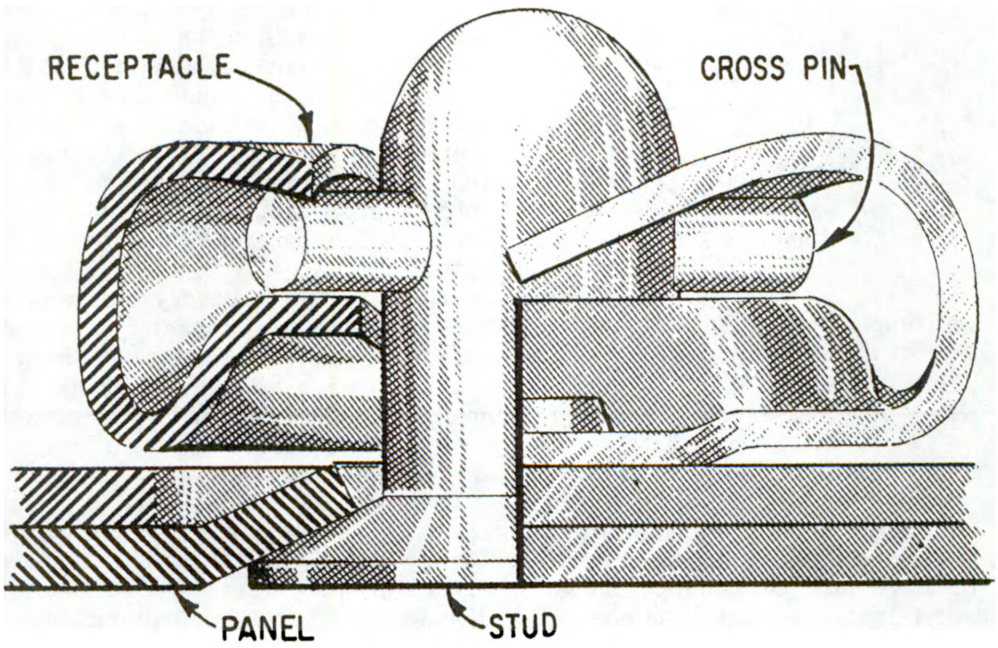


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Figure 3-21.—Airloc fastener.

THREADED FASTENERS

Threaded fasteners are covered in the Rate Training Manual Airman, NavPers 10307-C. However, a brief discussion of a new development in threaded fasteners is included in this text.

"Torq-Set" Screws

"Torq-Set" machine screws (offset cross-slot drive) have recently begun to appear in new equipment. The main advantage of the newer type is that more torque can be applied to its head while tightening or loosening than any other screw of comparable size and material without damaging the head of the screw.

Torq-Set machine screws are similar in appearance to the more familiar Phillips machine screws.

Since a Phillips driver could easily damage a Torq-Set screwhead, making it difficult if not impossible to remove the screw even if the proper tool is later used, maintenance personnel should be alerted to the differences. (See fig. 3-22.)

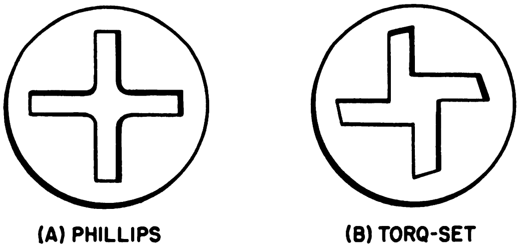

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Figure 3-22.—Comparison of Phillips and Torq-Set screwheads.

Torque Information

The torque table (table 3-2) may be used as a guide in tightening nuts, bolts, and screws whenever specific torque values are not called out in maintenance procedures. Using the proper torque allows the structure to develop its designed strength and greatly reduces the possibility of failure due to fatigue.

Threads must be free from grease or oil. Lubrication changes the torque value and will result in overtorquing.

When castellated nuts are used, they should be tightened to the lower torque limit; then continue tightening until the cotter pin hole is alined with slots in nut. Do not back off nut to aline hole.

When it is necessary to tighten from the bolthead, use the high side of the torque range. If necessary, the maximum allowable tightening torque may be used.

When corrosion-resistant steel bolts are used, they should be lubricated with an antiseize compound. Corrosion-resistant steel bolts and nuts must be used together. Use shear nut torque values when tightening these bolts.

CONNECTORS

In the discussion which follows, the word "connector" is used in a general sense. It applies equally well to connectors designated by "AN" numbers and those designated by "MS" numbers. AN numbers were formerly used for all supply items cataloged jointly by the Army and Navy. Many items, especially those of older design, continue to carry the AN designator, even though the supply system is shifting over to MS (Military Specfication) numbers.

Connector Construction

Electrical connectors are designed to provide a detachable means of coupling between major components of electrical and electronic equipment. These connectors are constructed to withstand the extreme operating conditions imposed by airborne service. They must make and hold electrical contact without excessive voltage drop despite extreme vibration, rapid shifts in temperature, and great changes in altitude.

These connectors vary widely in design and application. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut, and each consists of an aluminum shell containing an insulating insert which holds the current-carrying contacts. The plug is usually attached to a cable end and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected and is usually mounted on a part of the equipment.

There are wide variations in shell type, design, size, layout of contacts, and style of insert. Six types of connector shells are shown in figure 3-23.

Table 3-2.—Torque values in inch-pounds.

Wrench size (in.)	Standard nuts, bolts, and screws		
	Bolt, stud, or screw size	Tension type nuts AN310 and AN365	Shear type nuts AN320 and AN364
1/4	4-48	4-5.5	2.5-3.5
5/16	6-40	7.5-11	4.5-6.5
11/32	8-36	12-15	7-9
3/8	10-32	20-25	12-15
7/16	1/4-28	50-70	30-40
1/2	5/16-24	100-140	60-85
9/16	3/8-24	160-190	95-110
5/8	7/16-20	450-500	270-300
3/4	1/2-20	480-690	290-410
7/8	9/16-18	800-1,000	480-600
15/16	5/8-18	1,100-1,300	660-780
1 1/16	3/4-16	2,300-2,500	1,300-1,500
1 1/4	7/8-14	2,500-3,000	1,500-1,800
1 7/16	1-14	3,700-5,500	2,200-3,300

NOTE: To convert to foot-pounds, divide inch-pounds by 12.

Connectors MS 3100 is a wall-mounting receptacle. It is intended for use with conduit to eliminate the necessity of installing conduit boxes.

Connector MS 3101 is a cable-connecting receptacle, and is used with cable or in other installations where mounting provisions are not required.

MS 3102 is a box-mounting receptacle, and is intended for use where a detachable connection is required on a shielded box or unit of equipment.

MS 3106 is a straight plug which is used when circuits are to be connected where space limitations are not critical. It consists of a front shell (usually referred to as an "insert barrel"), a coupling ring, the insert, an insert retaining device, and a rear shell.

MS 3107, a quick-disconnect plug, is used where very rapid disconnections must be made. A special coupling device is used instead of a coupling ring; otherwise it is similar to MS 3106.

MS 3108, a 90° angle plug, is similar in construction to MS 3106 except that the rear shell

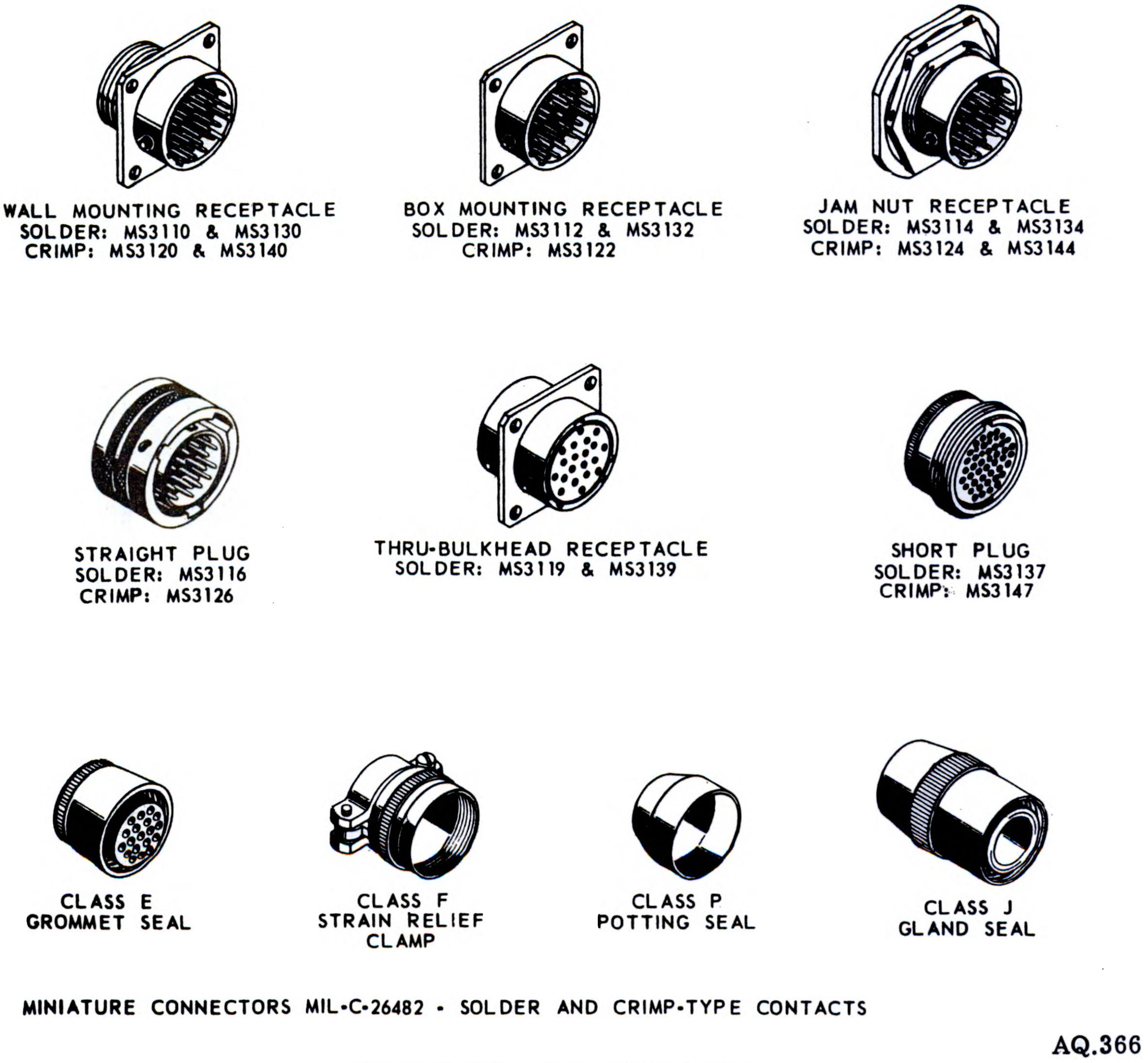


Figure 3-23.—Connector shells.

provides a right angle bend which is required where space is limited.

The shells of MS connectors are made in eight types, each for a particular kind of application. A letter designation is used in the MS number to indicate the shell design, as in MS 3106E, where E is the shell type indicator. The shell indicators are as follows:

A—Solid shell.
B—Split shell.
C—Pressurized type.
D—Sealed construction.
E—Environment resistant.
F—Vibration resistant.
H—Flame barrier shell.
K—Fireproof construction.

Solid shell connectors are used where no special requirements, such as fireproofing or moistureproofing, must be met. The rear shells are made from a single piece of aluminum.

Split shell connectors allow maximum accessibility to soldered connections. The rear shell is made in two halves, either of which may be removed. Figure 3-24 shows an exploded view of one type of a split-shell connector.

Pressurized connectors provide a pressure-tight feed-through for wires that pass through walls or bulkheads of pressurized compartments

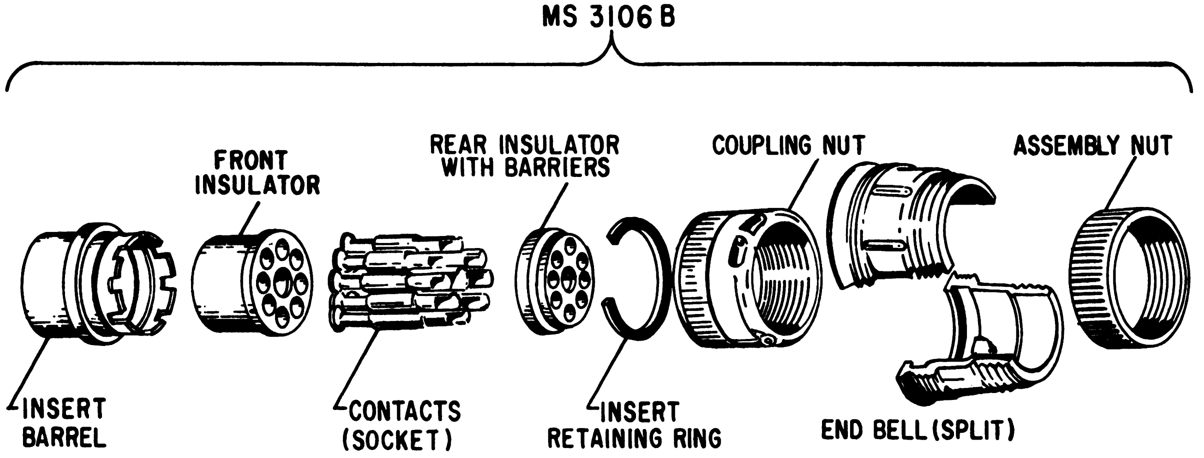


Figure 3-24.—Exploded view of a split-shell connector.

in high altitude aircraft. The contacts are usually molded into the insulator, and the shell is spun over the assembly to seal the bond.

Sealed connectors are employed in equipment that is sealed and operated under gas pressure. These connectors include a glass-to-metal seal and have either special rubber inserts or a cementing compound applied to the insert.

Vibration-resistant connectors are designed for use in equipment that is subjected to intense vibrations in installations on or near reciprocating engines.

Fireproof connectors are made under specifications which require that the connector maintain effective electrical service for a limited time even when exposed to fire. The inserts are made of a cermaic material, and special crimp type contacts are used.

Moisture-resistant connectors consist of a combination of the features of the solid shell, the pressurized, and the vibration-resistant types. The component parts of this kind of connector are shown in figure 3-25.

Each connector is given an identification symbol which is called the MS part number. This symbol indicates the shell type, the shell design, the size, the insert type, the insert style, and the insert position. An example is the designator MS 3100-A-16-11 PX.

The letters MS form the prefix. The number 3100 indicates the shell type and identifies the connector as one of the types shown in figure 3-23.

The letter A indicates a solid shell connector. The number 16 is the shell size.

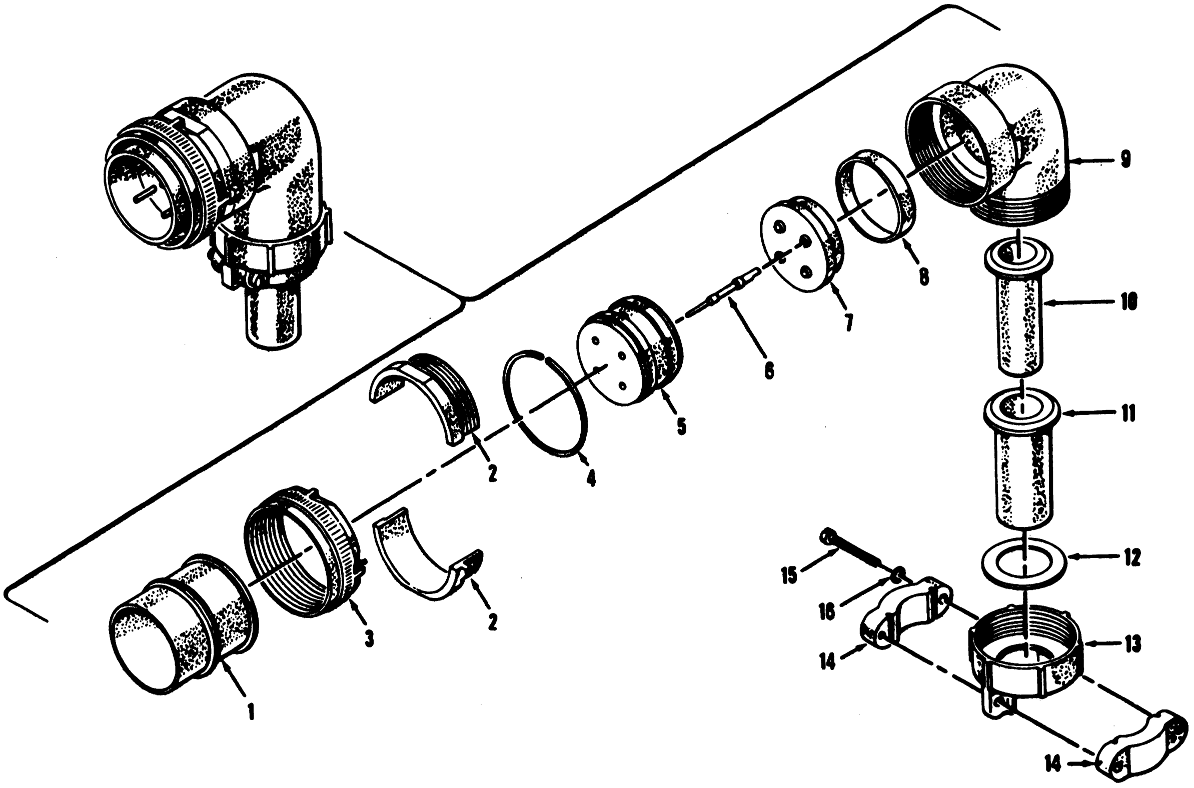
The number 11 is a designation of the insert pin arrangement used in the connector. A chart showing various pin arrangements may be found in the Operation and Service Instructions Manual, AN Electrical Connectors (AN-03-5-90).

The letter P means that the insert is a pin, or male, insert. (The letter S is used to indicate a socket, or female, insert.)

The concluding letter, X, is a designation of the insert position. Connectors specially designed for a particular application sometimes have nonstandard contact, or insert, positions. Four positions of the inserts are employed, and these are called W, X, Y, and Z. Each letter refers to an angle by which the insert is rotated from the standard position. When the standard position is employed, no letter is shown at the end of the MS designation.

Three common types of subminiature connectors are shown in figure 3-26. Since these connectors are the wire-connected type, they have no flanges for mounting. However, the receptacle shown in part (C) can be mounted with nuts and lockwashers. They are used on miniature instruments, switches, transformers, amplifiers, and relays.

The subminiature connectors described and shown in figure 3-26 have not proven sufficiently satisfactory and are not being used in new aircraft designs. Their use is limited to those aircraft in which they were initially installed.



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1. Insert barrel.
2. Split nut (half).
3. Coupling nut.
4. Split-nut retaining ring.
5. Insulator.
6. Contact (pin).
7. Grommet.
8. Ferrule.
9. Angle—90° end bell.
10. Telescoping gland busings.
11. Telescoping gland busings.
12. Bushing washers.
13. Gland-clamp fittings.
14. Clamp saddles.
15. Clamp-saddle screws.
16. Lockwashers.

Figure 3-25.—Exploded view of a 90° angle connector.

The new miniature connectors (MS 311X and 313X series) are intended to supersede these subminiature connectors. The new miniature connectors differ from the types just described in their method of coupling and contact sizes. Two types of quick-disconnect couplings are provided—axial and bayonet.

Through a reduction in size of contacts, from 0.062- to 0.040-inch diameter, a greater number of contacts per unit area can be achieved. The miniature connectors with smaller contacts rated at 7.5 amperes have found increased use through the advent of a-c power in aircraft, where the majority of the circuits are low power and low current. All these connectors are environment resisting Class E. Hermetic receptacles and connectors suitable for potting are also provided in this series.

Coaxial connectors are divided into series and are shown in figure 3-27. Each series consists of plugs, panel jacks, receptacles, and straight and right angle adapters.

Series UHF connectors are low-cost, general purpose connectors of nonconstant impedance. The small and large coaxial types are for use with small and medium size coaxial

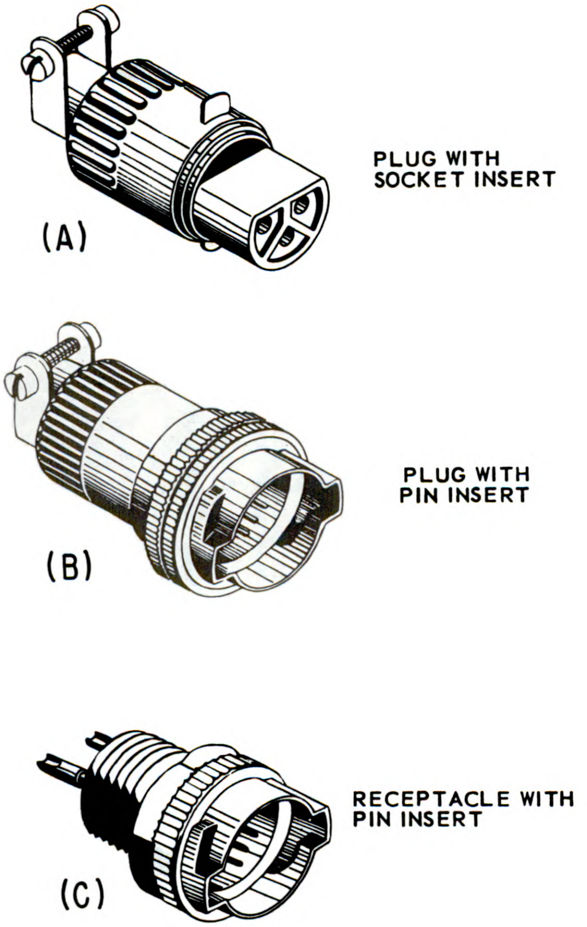

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Figure 3-26.—Subminiature connectors.

cables in applications where line imbalance or increased standing wave ratio is not important. Where impedance matching is necessary, C, N, or BNC series connectors are used. Both small and large series UHF connectors can be weatherproofed for outdoor use but most are nonweatherproof.

The twin connectors are similar to the series UHF connectors except for the fact that they have twin center conductors and are to be used with small and medium sized twin-conductor cables. Twin connectors are available in small weatherproof and nonweatherproof types and large nonweatherproof types.

Series N connectors are the most popular constant impedance connectors for medium size coaxial cables. They can be used up through microwave frequencies with minimum line imbalance or increase in standing-wave ratio. Although series N 50-ohm and 70-ohm connectors do not mate, 70-ohm cables may be used with 50-ohm series N connectors where impedance matching is not critical. Series N connectors are completely weatherproof.

Series C connectors are similar to 50-ohm series N connectors in that they are used with the same cables, are weatherproof, and can be used up through microwave frequencies. However, they are mechanically and electrically superior to series N connectors. Series C connectors feature bayonet-lock type coupling for quick connect and disconnect, an improved cable clamping mechanism for better cable grip with minimum cable indentation, and are intended for use up to 1,000 volts.

Series BNC connectors (fig. 3-28) are commonly used on small coaxial cables. All incorporate quick connect and disconnect bayonet-lock coupling and are weatherproof. Besides regular and modified low-voltage types of nonconstant impedance, improved series BNC connectors are available which have a constant 50-ohm impedance and yield excellent electrical performance up to 10,000 megahertz.

Series HN connectors are weatherproof, high-voltage connectors of constant impedance for use with 50-ohm RF cables.

Series LC connectors are large, 50-ohm, weatherproof connectors designed for applications involving the transmission of large amounts of RF power.

Series BN connectors are small, lightweight connectors (of non constant impedance) designed for use with the same coaxial cables which use BNC connectors. BN connectors are not recommended for applications at frequencies in excess of 200 megahertz unless electrical requirements of the circuit are not critical. They may be used at peak voltages up to 250 volts.

Series LT connectors are very similar in appearance to series LC; however, series LT differ not only in cable accommodation but are lighter than series LC connectors. Series LT connectors are large, 50-ohm, 5,000-volt connectors for use with Teflon RG-117/U cable.

Series TNC connectors are basically identical with series BNC connectors. The major difference is that TNC connectors have a threaded type coupling instead of the bayonet-lock coupling. Consequently, TNC connectors are usually preferred in applications which are subject to extreme vibration.

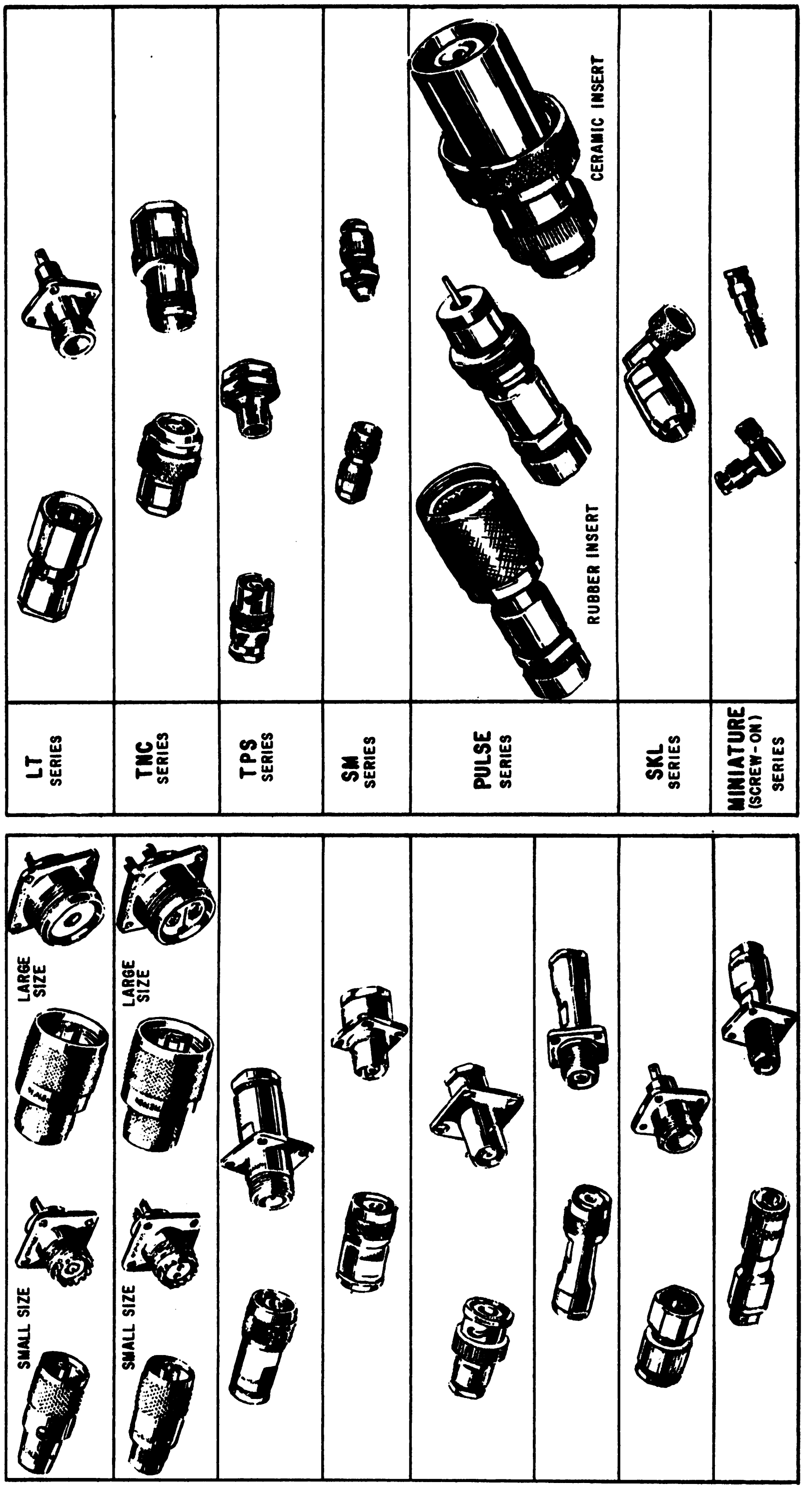

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Figure 3-27.—Several typical coaxial connectors.

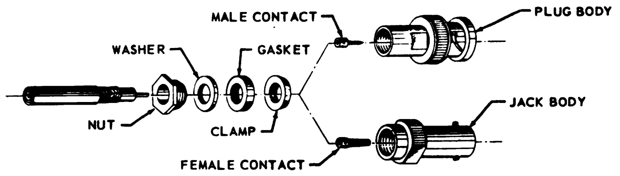

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Figure 3-28.—Exploded view of a standard BNC connector.

Series TPS connectors are weatherproof and designed to produce minimum electrical discontinuities in small size 50-ohm coaxial cable up to a frequency of 10,000 megahertz. The connectors are rated at 1,500 volts rms at sea level; their use is governed by the temperature limitations of their associated cables.

Series SM connectors are nonweatherproof fittings for coaxial cables of 1/4-inch overall diameter and smaller. They may be used where electrical matching is not required. The SM connectors are smaller and contain fewer parts than the BNC series. The SM series employs a female center-conductor contact on plugs and a male center-conductor contact on jacks and receptacles. However, for consistency in cataloging and usage, a plug is still regarded as having a male mating end and a receptacle or jack as female. The SM series is not intended to replace the BNC series except for internal equipment connections where weatherproofness is required.

The pulse connectors are designed for high-voltage pulse or direct-current applications. They are nearly all weatherproof and available in three types—rubber-insert, ceramic-insert, triaxial. The rubber-insert type PULSE connectors have a peak voltage rating of 5,000 volts at an altitude of 50,000 feet. They are designed principally for use with cables having an insulated Neoprene layer under the braid, such as RG-77/U and -78/U.

They may be used with cables employing a conducting rubber under the braid (such as RG-25/U, -26/U, and -64/U) provided special care is taken in assembling the connectors to these. The ceramic-insert pulse connectors are available in small (type A) and large (type B) sizes. Type A connectors are designed for use with the 8,000-volt RG-25/U, -26/U and type B with the 15,000-volt RG-27/U, -28/U cables. (Special care is required when assembling connectors to these.) Pulse connectors tend to leak noise which may interfere with communications equipment. Triaxial connectors are used in transmission line applications where maximum RF shielding and minimum noise radiation are required. They are commercially available in sizes of the same diameter as the BNC series and C series (and possibly others). Some of these connectors have been used in military equipment and some within-series adapters are commercially available.

The SKL connectors were originally designed to provide a connection to a klystron tube. Newer klystrons are being equipped with BNC connectors. Various modifications were subsequently designed to provide general purpose cable-to-cable connections and adapters.

Miniature connectors have a gold finish, employ screw type coupling, and Teflon dielectric. They have a nominal impedance of 50 ohms, a sea-level breakdown voltage of 1,500 volts rms, a practical frequency limit of 10,000 megahertz, and are designed for operation up to 200°C.

WIRE

Although modern technical literature has been emphasizing the use of printed circuits and microelectronic components in contemporary electronic equipment, wire is still important as a signal or current carrying device. Therefore wire does deserve appropriate attention.

Since most naval equipment is of conventional construction, and complete conversion to the new forms of conducting components is not yet imminent, traditional wire conductors are in use, and probably will continue to be in use for some time to come. This means that when wire is to be requisitioned, either for installation or repair, care must be exercised in its selection. The three major factors involved in this selection, in descending order of importance, are size, insulation, and the characteristics required to satisfy specific environments in which the wire must function. Wire is discussed in detail in chapter 18 of this manual.

COAXIAL CABLES

Flexible coaxial cables (sometimes called RF cables) are a special type of cable used for carrying video and RF signals, cathode-ray-tube sweep currents and voltages, trigger range marks, blanking pulses, and other signals for radar receivers, transmitters, and indicators. These cables are constructed with special considerations for shielding, impedance, capacitance, and attenuation. All of these factors are of importance in many circuits. Coaxial cables have neither induction nor radiation losses. These lines have low attenuation even at very high frequencies and are used as high as 3000 MHz.

The name coaxial is derived from the construction, in that the inner and outer conductors have a common axis or coaxis. These cables consist of an inner conductor, a dielectric insulator, an outer conductor, and an outer covering. The inner conductor is usually made of copper—plain, tinned, or silver coated. The dielectric insulation is usually polyethylene, although other materials are used. The outer conductor is made of a single or double braid of plain, tinned, or silver-coated copper. The outer covering is made of a synthetic resin (vinyl), Teflon tape, or chloroprene. This covering serves both as weatherproofing and protection from mechanical abuse.

Flexible coaxial cables are classified in four groups; namely, general purpose, high temperature, pulse, and special characteristics. The general purpose cables consist of various sizes of cables as just described. The high temperature cable is basically the same but usually has a dielectric made of Teflon, and the outer covering is made of Teflon tape and fiberglass braid which enables it to withstand increased temperatures. Pulse cables have the ability to withstand high voltages because of conductor spacing and the type of dielectric used in their construction.

The special characteristics cables are made of various materials and sizes of inner conductor, outer conductor, dielectric, and outer covering. By varying these parts, the capacitance, impedance, shielding, attenuation, voltage rating, and the ability to withstand weather and abuse are varied to fit the required qualities. With exception of the special characteristics type, these coaxial cables have an impedance of 50 to 75 ohms. The impedance of the special characteristics type is often much higher. An example is the RG-65A/U which has an approximate impedance of 950 ohms and is used as a high impedance video cable. In replacing a coaxial cable, care should be exercised to use the correct replacement, otherwise most of the advantages of coaxial cables are lost.

At frequencies near 3000 MHz, flexible coaxial cables have appreciable losses. At these frequencies, rigid coaxial cables are used with air as the dielectric. The inner conductor is supported by ceramic or polystyrene beads.

SUBSTITUTION OF PARTS

If the specified parts cannot be obtained, a temporary installation may be made using suitable substitute parts, but these parts should be replaced with the proper items as soon as they can be obtained. When making parts substitutions, special attention must be given to the following considerations:

1. Corrosion. The chemical or metallic composition of the part must be such that its use does not contribute appreciably to the danger of corrosion.
2. Strength. The strength of the substitute part must be the same, or greater than the ones prescribed. (When determining the strength, consideration should be given to the tensile, compression, and/or shear strength, as applicable to the specific use.)
3. Size. Substitute bolts and screws should be the same size as the prescribed item. If a detachable nut is to be used, a different thread may be tolerated; if a threaded hole or an anchor nut is involved, the thread must be the same as the one prescribed. In all cases, washers must have the same inner diameter as the prescribed item, but a different outer diameter or thickness may sometimes be permitted.
4. Length. Substitute screws or bolts must have a length which is sufficient for the particular installation, but must not be so long that they are in the path of any moving part. They must not be in contact with other aircraft items such as electrical wiring, hydraulic lines, etc.
5. Magnetic properties. Specific areas of the aircraft (for example, vicinity of such items as the magnetic compass, magnetic anomaly detection equipment, radio direction finder, or gyros) should not be changed in a manner that may cause the magnetic fields of the area to become distorted. In these areas, any substitute part must possess the same magnetic properties and characteristics as the one prescribed.
6. Style. Most items of mounting hardware are available in various styles. It is usually easy to find screws and bolts which are identical in all respects except for the type head. These parts are usually to be preferred as substitutes,

provided they possess all the required special features.

7. Special features. If a bolt is to be torqued to a given value, a torque wrench which is usable with that type part and which has the proper torque range must be available. If lockwiring is required, the part must have suitable provisions.

8. Lubrication or coating. If specific instructions call for lubrication or coating of the parts, they must be followed for the substitute part as well as for the prescribed part. If no lubrication is permitted, the substitute part is not to be lubricated.

SOLDER

Two types of solder are available—the tin-lead alloy known as soft solder and the so-called hard or silver solder. Soft solder alloys permit the use of lower soldering temperatures and are therefore recommended for electronic applications. Where a joint of greater strength is required, silver solder is employed.

Most solder alloys do not liquefy immediately as the temperature is increased. Ordinarily they change from the solid state to a plastic or semiliquid, and finally become completely liquid. Most tin-lead solders enter the plastic state at 358°F and become wholly liquid at various temperatures, dependent upon the individual composition. A combination of 63 percent tin and 37 percent lead has the lowest melting point (361°F) for the tin-lead group. However, since it changes from solid to liquid without an intervening plastic state, it is susceptible to fracture from slight vibration while cooling.

(Solder is commonly referred to as 70/30, 60/40, etc. This is the tin-lead content.)

FLUXES

All common metals are covered with a nonmetallic film, usually an oxide of the material, which prevents them from making the intimate contact so necessary for a good electrical connection. The purpose of a flux is to remove the oxide from the surfaces to be soldered, not to clean them. Flux cannot replace good cleaning methods in preparing surfaces for soldering. Without a clean, intimate contact, poor soldering techniques may result in a mechanically weak, high resistance joint—a so-called rosin joint in the case of rosin-base flux.

Solder fluxes may be divided into three general groups—rosin, organic, and chloride (sometimes called acid). The residue from the rosin-base fluxes is noncorrosive and electrically nonconductive, making them highly acceptable for use in military electronic equipment. The organic and chloride types are seldom used (sometimes even prohibited) because of their corrosiveness. Actually, only rosin-base flux is recommended for electronic applications.

Activated or intensified rosin-alcohol fluxes are permitted by MIL-S-6872 if they are noncorrosive. (For details, consult this specification.)

ORGANIC fluxes consist of mild organic acids and bases. These fluxes are almost as active as the organic salts, but their period of activity is brief due to their susceptibility to thermal decomposition. This limits corrosion and therefore may be used in applications where the soldered assembly lends itself to residue removal.

CHLORIDE type fluxes are not recommended for electronic applications.

POTTING COMPOUND

Most electrical connectors and some relays used in aircraft are potted to prevent corrosion, contamination, or arc-over between pins and terminals. Because of temperature variations throughout the aircraft, two different potting compounds are used—one is tan and the other red. The temperature range of the potting compound can be determined from its color. The tan compound is used where the temperature under operating conditions does not exceed 87.8°C (190°F). The red compound is used where the temperature is higher. Should it become necessary to replace or repot a relay or connector, the potting compound used should have the same temperature range (color) as the original material. Care should also be taken to duplicate the shape of the original potting so that no installation problems will occur.

A detailed discussion of the procedures to be followed in the potting of a connector is presented in chapter 18 of this manual.

ACCOUNTABILITY

A definition of the word accountability is "the state or quality of being responsible—a charge (object) for which one is responsible or accountable." The Navy has a code that is called

Material Accountability Recoverability Codes (MARC's). These codes appear in column 3 of the Section G Allowance List, NavAir 00-35-QG-0 Series and are illustrated by the following examples:

Code:

B—Exchange consumables—requiring old items for replacement items such as items containing precious metal, highly pilferable items, or certain high cost items. Example: Drill, electric portable, FSN 9Q 5130-226-5384.

C—Consumables—expendables. Example: Stripper, Wire, FSN 9Q 5110-268-4220.

ALLOWANCE LISTS

Allowance lists are lists of equipments, material, and/or tools made available to an organization for performance of maintenance.

NavAir 00-35QG-0 Series

These allowance lists contain allowances of shop and general support equipment and material which will be made available for maintenance support of aircraft as may be assigned or supported by the following levels of maintenance:

1. Intermediate level (shop).
2. Organizational level (hangar/line).
3. Advanced base components, excluding Aircraft Fleet Marine Force activities supported by tables of basic allowances.

CUSTODIAL RESPONSIBILITY

Most handtools are not feasibly repairable. Due to this fact and their original low cost (compared to shop tools), they are classed as consumable. However, the activity must pay for replacements. Therefore, it is the duty of each individual to help eliminate the need for replacements. One method of accomplishing this is by carrying an inventory of tools in your toolbox so that upon completion of a job you can be sure that all of the tools are accounted for. A tool that has been lost represents a waste of funds; in addition, it is a definite liability. If it has been left loose in an aircraft, it can become a dangerous missile when the aircraft is launched or when the aircraft is performing violent maneuvers.

Inventory Requirements

The basic objective of an inventory is to insure a proper balance between the supply of, and the demand for, those tools required for the efficient operation and maintenance of a squadron or maintenance activity. To accomplish this objective it is necessary that tools be identified and cataloged to provide accurate knowledge of the tools being used. Each item should be accounted for every 30 to 90 days in accordance with squadron instructions. The number of handtools on hand in relation to the number required by the activity should be indicated by the inventory.

Reordering Tools

Tools are reordered as the inventory requirements dictate. Usually the senior petty officer or his delegate reorders all tools—both shop tools and those for individual toolboxes, as they are needed. However, squadron or maintenance activity policy is followed in all cases.

It is unwise to wait until the number of tools needed is too large, as it is easier for the supply department to fill a small order rather than a large one.

Tools are ordered by reference to Consumable General Support Equipment for All Types, Classes, and Models of Aircraft, NavAir 00-35QG-016.

MATERIAL REQUISITIONING

Maintenance personnel are likely to encounter a variety of local requisitioning channels, all designed to present a demand for an item to the supporting supply department. Assigned levels of maintenance, geographical location of shops relative to supply facilities, and mission of activities requiring support all influence the local requisitioning channels. Local instructions normally promulgate detailed procedures for submitting your demand to the appropriate supply point.

SUPPLY ACTIVITY

The mission of the supply activity is to support the operational and maintenance efforts of the activity or ship. Stocks of aviation oriented material carried are tailored and replenished to this end. Positioning, replenishment, and control of stocks of material in maintenance areas are carried out as a result of joint decisions by the supply and maintenance officers concerned. They determine the range, depth, and related procedures. The cost of material used in maintenance is totaled so that the costs of maintaining a weapons system can be determined. This data is used as an inventory management tool to determine geographic and strategic distribution of stocks of material.

Supply Support Center

Maintenance organizations have one single point of contact with the supporting supply activity. This single supply contact point is the Supply Support Center (SSC) which responds to all material requirements of the maintenance organizations. The SSC is an internal organization of the local supply activity. It is made up of two sections—the Supply Response Section (SRS), and the Component Control Section (CCS).

Supply support is available consistent with the operating hours of the maintenance activities supported. If maintenance is being performed 24 hours a day, then supply support is available 24 hours a day.

The supply support center maintains rotatable pool material which consists of repairable ready-for-issue items reserved primarily to satisfy the requirements of organizational level maintenance. Items maintained in the pool are capable of being repaired by the local intermediate maintenance activity, have application relationship to weapon systems supported by local intermediate maintenance activities, and have and average organizational maintenance level removal rate of at least one per month. Defective components are turned in to intermediate level maintenance for repair. The defective components repaired to an RFI condition are then returned to the rotatable pool to replace the components previously issued.

Low value, fast moving consumable items are preexpended from supply. Such materials are located in the maintenance area. The establishment, maintenance, and replenishment of preexpended bins are the responsibility of the supply organization.

SUPPLY RESPONSE SECTION.—The Supply Response Section (SRS) is responsible for preparing all necessary requisitions (DD Form 1348) and related documents required to obtain material for local maintenance use in direct support of weapon system maintenance. The maintenance organization verbally notifies the supply organization of the need for such material. When material is available locally, the time frame for processing and delivery is as follows:

Priority	Process/Delivery Time
1-3	1 hour
4-8	2 hours
9-20	24 hours

Otherwise, the time frames as noted in table 3-3 will apply.

The SRS is responsible for receipt, storage, and issuance of all ready-for-issue pool components. It is responsible for physical delivery of RFI material to maintenance organizations, and the pickup of defective components from the organizational maintenance activity and subsequent delivery to the intermediate maintenance activity. Actual maintenance personnel are not involved in the physical movement of material between organizations.

This section also performs technical research in regard to completion of requisition documents as well as determining the status of outstanding requisitions and relaying this status to the customer upon request.

COMPONENT CONTROL SECTION.—The Component Control Section (CCS) accounts for all components being processed in the intermediate maintenance activities. This section also records on the status of all rotatable pool components.

Table 3-3.—Processing time frames.

Issue Group	Issue Priority Designator Range	Supply Source Processing	CONUS On Station Time	Overseas On Station Time
1	1-3	24 hours 24-hour day 7-day workweek	120 hours	168 hours
2	4-8	72 hours 24-hour day 7-day workweek	8 days	15 days
3	9-15	10 days 8-hour day 5-day workweek	20 days	45 days
4	16-20	12 days 8-hour day 5-day workweek	30 days	60 days

CHAPTER 4

PUBLICATIONS, DRAWINGS, AND SCHEMATICS

There are many publications utilized in the proper maintenance of a weapons system. The weapons systems in modern day aircraft have become so complex that maintenance is practically impossible without the use of technical publications. Even a mere listing of the electronics equipment installed in modern day aircraft would be quite lengthy. It is impossible for any one individual to be thoroughly familiar with all the various types of electronics equipment in present use; but with a good general background of electronic principles and circuit theory, a little study will enable the technician to rapidly familiarize himself with any specific equipment.

The purpose of this chapter is to discuss some of the sources of information available, how to use these references, and how to locate details on items of information the AQ needs in the performance of his duties.

Included in this chapter are discussions of publications, both general and specific; drawings and schematics, including illustrations, block diagrams, and wiring and cabling diagrams; charts and tables; and a brief coverage of procedures for the handling of classified materials and information.

PUBLICATIONS

Publications dealing primarily with the operation and maintenance of aircraft and related equipment within the Naval Establishment originate from the Naval Air Systems Command (NASC) and are issued by authority of the Commander, Naval Air Systems Command.

Publications concerned mainly with the training of flight personnel and air operations emanate from the Office of the Deputy Chief of Naval Operations (AIR).

The Naval Air Technical Services Facility functions as the sponsor of both types of publications and controls the initial distribution, distribution lists, printing, and retention of reproducible copy.

The Forms and Publications Supply Office functions as inventory manager for residual stocks of both types of publications, including the supporting distribution systems and numerical cataloging.

The basic sources of technical aeronautic information are the technical manuals (formerly called handbooks) issued by NASC. Letter publications usually supplement the information contained in aeronautic technical manuals.

Technicians at the E-4 and E-5 levels are primarily concerned with technical publications; therefore this discussion is directed mainly toward them. However, it includes some coverage of general and administrative type publications of importance to all naval personnel.

Good technical manuals are vital to the maintenance of modern weapons systems. Our Navy's combat readiness depends, to an increasing degree, on the information and knowledge possessed by maintenance personnel. If these men are to maintain increasingly complex weapons systems, incorporating the latest devices and systems, they must be able to obtain the required information from technical manuals.

The Department of Defense, the Department of the Navy, and the Naval Air Systems Command are working together to improve the standardization and quality of aeronautic maintenance manuals. The purpose of the following discussion is to present some detailed information concerning the contents and uses of these manuals.

PUBLICATIONS LISTS AND INDEXES

Aeronautic publications originated by the Naval Air Systems Command and distributed by the Naval Air Technical Services Facility are covered by separate lists and indexes as listed below:

1. Navy Stock List of Forms and Publications, NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part C. This stock list contains a numerical listing by code numbers and latest issue date of available aeronautic

technical manual type publications. The date indicates the date of either the basic book, latest change, or revision.

2. Navy Stock List of Forms and Publications, NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part D. This stock list contains a listing of latest dates of aeronautic letter type publications.

NOTE: These stock lists are prepared by the Forms and Publications Supply Office, Byron, Georgia, and distributed to the mailing list maintained by the Naval Air Technical Services Facility, 700 Robbins Avenue, Philadelphia, Pa. 19111.

The Naval Aeronautic Publications Index consists of the following four parts:

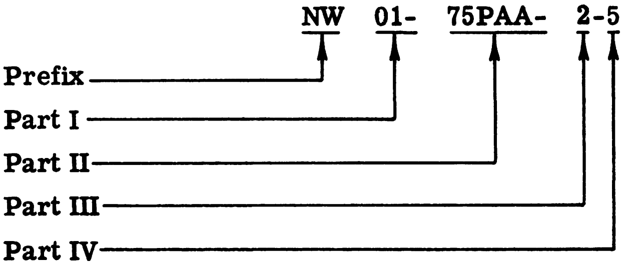
1. NavSup 2002, Section VIII, Parts C and D—Numerical Sequence List. Issued semiannually and supplemented bimonthly.
2. NavAir 00-500A—Equipment and Subject Applicability List. Issued semiannually and supplemented bimonthly.
3. NavAir 00-500B—Aircraft Application List. Issued semiannually and has no supplement.
4. NavAir 00-500C—Directives Application List. Issued semiannually and has no supplement.

The Equipment and Subject Applicability List, NavAir 00-500A, lists aircraft components and related equipment by model, type, and part number in alphabetical and numerical sequence with the applicable publications shown in appropriate columns. The Aircraft Application List, NavAir 00-500B, lists aeronautic manual publications with respect to their application to specific aircraft. It lists technical manuals dealing with electronics, armament, instruments, accessories, powerplants, aircraft, and certain general publications. It does not list letter type publications. The Directives Application List, NavAir 00-500C, lists active NavAir letter type publications and technical directives with respect to their applicability to specific aircraft.

NUMBERING SYSTEM FOR MANUALS

Publications issued by NASC are designated according to a numbering system based on the type publication and its material content. The system cannot be described fully in this course because of its complex nature and many exceptions.

Coded designations assigned to technical manuals consist of a prefix and an alphanumeric sequence of three or four parts. The example shown below will be used to explain the system for designation of technical manuals:



Prefix

The prefix may consist of the letters NavAer (often shortened to NA), NavAir (also shortened to NA), NavWeps (normally shortened to NW), AN, TO, or CO. NavAer manuals were published by the Bureau of Aeronautics before the establishment of the Bureau of Naval Weapons. Manuals published after the establishment of the Naval Air Systems Command are identified by the prefix NavAir.

The prefix AN was previously assigned for technical manuals used jointly by the Navy and the Air Force; they were prepared to coordinate military specifications.

TO was the prefix assigned to technical manuals originated by the Air Force.

CO was previously used to designate a technical manual with a Confidential security classification.

These prefixes, while no longer assigned for new material, will remain in effect for existing assignments until superseded.

Part I

Part I consists of numbers to identify the general subject classification with the basic subject to which they pertain. These numbers usually have two digits; however, when an additional classification breakdown is necessary, Part I consists of two digits followed by a letter. An example of this is found in the 02 (Powerplants) series. A typical entry in this series has the number 02B immediately following the prefix NW. In this example, the B identifies the powerplant as a jet propulsion type.

Table 4-1 lists the general subject categories and their numerical equivalents. In

Table 4-1.—Subject categories and code numbers for aeronautic manuals.

General	00
Allowance lists	00-35Q
Training publications (aviation)	00-80
Aircraft	01
Powerplants	02
Accessories	03
Hardware and rubber	04
Instruments	05
Fuels, lubricants, and gases	06
Dopes and paints	07
Ground servicing and automotive equipment	08-20, 14 & 19
Photography	10
Armament	11
Fuel and oil handling equipment	12
Parachute and personal equipment	13
Standard preservation and packaging instructions	15
Electronics	08 & 16
Machinery, tools, and test equipment	17 & 18
Descriptive data for aviation support equipment	20
Chemical equipment	24 & 39
Instructional equipment and training aids	09 & 28
Meteorology (aerology)	50
Ships installations	51

some instances, it will be noted that an equipment category has more than one numerical equivalent. In the case of electronics, which carries the codes 08 and 16, the equipment category is in the process of subdivision or change.

Part II

Part II of the publication number consists of numbers (or numbers and letters) and indicates the specific class, group, type, or model and manufacturer of the equipment. The subject breakdowns are listed at the beginning of each separate major division within NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part C.

For aircraft manuals and equipment manuals, this part will be explained in more detail later.

Part III

Part III consists of a number or numbers which designate a specific manual. For airframes and engines, this part designates a specific type manual. For other types of equipment, this part is assigned in numerical sequence and has no direct reference to the type of manual.

Part IV

Part IV pertains only to certain specific classes of manuals (such as the Maintenance Instructions Manuals for aircraft), and designates a particular manual of a set. Numbering is not completely standardized, and may have decimal or even double decimal suffixes. The exact volume desired may be determined from the lists or indexes of publications.

AIRCRAFT MANUALS

Aircraft manuals are prepared by the manufacturer and published for each aircraft model in naval use. The manual for a particular aircraft model consists of a series of individual publications, each dealing with a definite phase of the overall operation or maintenance program. As indicated in the preceding discussion, aircraft manuals fall into the NavWeps 01- (Series) category, and manuals pertaining to a particular model may be identified by an alphanumeric designator immediately following the 01-.

NavAir 01- (Series) Manuals

Aircraft technical manuals are of several different types, some of which are of extreme importance to the maintenance technician in the routine performance of his normal duties. These types are discussed in some detail in this chapter. Manuals of some other types are of limited importance to avionics personnel, and are discussed only briefly.

Using the previous example of manual designation, the aircraft model to which a manual applies may be determined from Part II of the designator. The numbers are coded to indicate the specific manufacturer, and the letters indicate the particular aircraft model.

GENERAL AIRCRAFT MANUALS.—The NavAir 01-1 (Series) manuals do not apply to specific aircraft, but present some aspect of construction, operation, maintenance, repair, or inspection applicable to many models of aircraft. Some important examples of this type manual are NavAir 01-1A-505 (Installation Practices: Aircraft Electric and Electronics Wiring); NavAir 01-1A-506 (Handbook Aircraft Maintenance Cleaning); and NavWeps 01-1A-509 (Handbook Corrosion Control for Aircraft).

FLIGHT MANUALS.—Manuals of this class are identified by the number 1 in Part III of the standard nomenclature. For a given model aircraft, the complete flight manual usually comprises the standard NATOPS manual, pocket checklist, and classified supplements. Although this series is of primary interest to the pilot and aircrew, much of the information is of general interest to all personnel concerned in any manner with that aircraft. One section of special interest to avionics personnel is the functional operation of the electronics equipment installed.

STRUCTURAL REPAIR.—Structural Repair Manuals (identified by the number 3 in Part III of the standard nomenclature) usually comprise two manuals. The -3-1 manual is for use by organizational and intermediate level maintenance activities, while the -3-2 manual is for use by depot level maintenance activities. These manuals prescribe procedures and methods for making repairs to structural components of the aircraft.

MISCELLANEOUS MANUALS.—Although the contents of most other aircraft manuals are standardized, the numbering system is not. Some typical examples are the Special Weapons Check List, Special Stores, Assembly Procedures (for guided missile and target aircraft), Source Coded Data, Component and Shop Repair Data, etc. Some aircraft have only a few manuals of this type; others have many.

Maintenance Instructions Manual (MIM)

For this type manual, Part III of the standard designator is the number 2. The MIM comprises a variable number of individual publications, each dealing with some portion of the overall maintenance effort for the applicable model aircraft. The MIM (formerly called Handbooks of Maintenance Instructions) provides information concerning the location, functions, operation, removal, installation, testing, adjusting, and troubleshooting of components. Maintenance methods recommended are concerned with procedures such as those which can be performed by an operating squadron.

These manuals provide the technician with an invaluable aid in locating equipment components and interconnecting cables in the aircraft, and for inspection purposes as well as troubleshooting.

Before attempting any task on an aircraft, the Maintenance Instructions Manual for that particular aircraft should be consulted. By proper use of this manual, possible damage may be prevented and much time may be saved. Recommended maintenance methods are concerned with procedures which can be accomplished by operating units, and include a Quality Assurance Summary, which indicates the minimum quality control inspection requirements for each maintenance task.

In the past, these manuals were issued as a single complete unit. They were arranged so that the pertinent sections could be removed and kept available in the shop. At present, the separate sections of these manuals are being issued as separate publications under individual identifying numbers. This facilitates procurement, storage, filing, and use of specific parts of the manual by maintenance personnel.

Avionics maintenance personnel are concerned most often with the sections covering electrical and electronic systems, radio and radar, and wiring data.

NUMBER BREAKDOWN.—Part IV of the standard designator for an aircraft Maintenance Instructions Manual indicates the subject content of the manual. This designator may consist of a single number, a number and decimal, or even a number with double decimals, as required to break down the information sufficiently. Due to the differences in operational usage of various models of aircraft, this system cannot be standardized completely. However, the following partial listing is typical for many of the new aircraft:

- -2—Airframe Maintenance Instructions Manual
  - -0—Maintenance Planning Data (For some models of aircraft, this data is contained in a -100 publication rather than in -2-0.)
  - -1.1—General Information and Servicing
  - -1.2—Corrosion Control and Decontamination
  - -2—Airframe Systems
  - -3—Powerplant and Related Systems
  - -4—Instrument Systems
  - -5—Electrical Systems
  - -5.1—Electrical Power Supply System
  - -5.2—Lighting System
  - -6—Electronic Systems
  - -7—Armament and Related Systems
  - -8—Airborne Missile Control Systems
  - -9—Systems Integration
  - -10—Wiring Diagrams
  - -10.1—Wiring Data Diagrams
  - -10.2—Wiring Data Repair

Each category may be broken down into single or double decimal subdivisions as the occasion requires.

MANUAL BREAKDOWN.—The typical volume of the MIM contains six sections as follows:

Section I—Introduction. Provides a general description of the manual, including the scope of coverage, format, and arrangement of the included information. It contains listings of applicable publications and technical directives required by operating activities pertaining to the specific model aircraft or equipment covered in the manual.

Section II—Description and Operation. Includes a physical description of the aircraft or equipment covered by the manual. It includes a detailed listing of components, with separate tables for equipment components, tube and transistor complements, and fuses and circuit breakers. For equipments, this section also incorporates detailed information regarding input and output characteristics and requirements and operating instructions. Also included is a brief discussion on the theory of operation, definition of terms, explanation of terms and symbols, simplified and partial functional diagrams, and built-in test (BIT) features.

Section III—Organizational Maintenance (Line and Hangar). Describes that type of maintenance performed by the operating unit on a day-to-day basis in support of its own operations. This maintenance includes line operations (servicing, daily/preflight inspections, minor adjustments, etc., in preparation for flight), periodic inspections of aircraft and installed equipment and the associated tests, repairs, and adjustments.

This section includes such information as a tools and equipment list, manpower requirements, and test procedures. In addition, it includes system troubleshooting charts, test equipment hookups, and equipment voltage and resistance tables, assembly diagrams, etc.

Sections IV and V—Intermediate Maintenance (Component Repair) (Section V is not always included.) Some manuals combine all functions of maintenance into a single publication; others have various breakdowns. When this level of maintenance is included, the detailed contents parallel those of Section IV, except that the procedures for individual components (rather than the complete unit), are discussed.

Section VI—Diagrams. Contains the complete set of wiring and schematic diagrams for those units covered in the manual.

Illustrated Parts Breakdown (IPB)

The Illustrated Parts Breakdown normally consists of several individual manuals: one for each major functional element of the aircraft, and a final volume which is an index. It is identified by the -4 following the aircraft designation in the standardized publication identification system. It is useful in the procurement, requisitioning, storing, issuing, and identification of new or reclaimed parts.

It can also be used to determine the exact part or item required for replacement in a repair situation. It can also be used as a guide in reassembly of units which have been disassembled for testing, cleaning, or repair.

The separation of the IPB into its separate manuals does not necessarily follow the same order as the MIM breakdown; however, the type information available is consistent for nearly all IPB's.

MANUAL BREAKDOWN.—With the exception of the Index volume, each volume of the IPB follows generally the same format. It is divided into two sections—Introduction and Group Assembly Parts List.

Section I—Introduction. Contains specific detailed instructions for use of the particular IPB and the set to which it belongs.

Section II—Group Assembly Parts List. Provides reference and identification data for the various assemblies and subassemblies within the scope of the manual. For each assembly and subassembly, the data consists of a diagram and list. (See figs. 4-1 and 4-2.) The diagram indicates the location and general appearance of the item and provides clues for assembling. (Note the cutaway view, index No. 7A, used in the figure 4-1.)

Inserts illustrate items which are subassemblies of the major item. In the "description" column of figure 4-2 note the progressive indentations. The first entry is the complete assembly, and is begun flush at the left. Index numbers 1, 2, 3, etc., refer to individual items of material which are parts of the control panel assembly, and are indented. Further disassembly would be indicated by additional breakdown of one of the subassemblies, and the parts description would be progressively indented in the listing.

Note also the system used to identify attaching parts. Index number 16 is the radar control panel bumper, and the attaching parts are indexed as number 17. This shows that these items are used to attach item 16 behind the control panel assembly. As shown in figure 4-1, the bolt, nut, and cotter pin are listed as a single item having a single index number. In figure 4-2 the parts are listed separately, and each individual part is fully identified and described. In this case, the words "attaching parts" are enclosed in parentheses and are inserted in the listing immediately following the item they are used to attach.

The listing furnishes the details regarding the bits and pieces which make up the unit and is divided into five columns.

Column 1 gives the figure and index number. This number is a three-part sequence with hyphens separating the parts. The first part references the volume or major subdivision of the IPB. The second part indicates the number of the figure referenced. The third part indicates the callout number of the specific piece to which the other information pertains. The first entry always indicates the complete subassembly, and does not normally include the third part of the sequence.

Column 2 gives the part number for the specific item. This part number is used in conjunction with the Index volume of the IPB for stock number identification.

Column 3—Description. Provides the item name, manufacturer's code number (identifiable in the vendor's listing included in Section I), specification drawings, additional breakdown reference figures, and other pertinent data.

Column 4—Units Per Assembly. Specifies the total number of a given item in a single assembly.

Column 5—Usable on Code. When a specific item is used on certain aircraft of a given model, and a different item is used on other aircraft of the same model, this column is used. When all models use the same item, this column is left blank. The coding is explained in the Introduction, Section I.

The first figure of each volume is normally of the aircraft, showing the location of the major items of the aircraft. The callout numbers are referenced in the accompanying table, and are cross indexed with the applicable IPB figure number; this table gives no details except the title of the item or assembly. This figure and table are actually included in the Introduction, Section I.

INDEX BREAKDOWN.—The Index volume of the IPB comprises three sections—Introduction, Numerical Index, and Reference Designation Index.

Section I—Introduction. Contains details on the contents and arrangement of the volume.

Section II—Numerical Index. Consists of a numerical index containing all items listed in the Group Assembly Parts Lists of the preceding volumes. It is divided into two parts: The first part lists all the contractor part numbers, and the second part lists all the standard and vendor part numbers. Each part of the section is divided into five columns: Part Number, Federal Stock Number, Volume Figure and Index Number, Source Code, and Accountability/Recovery Code.

Section III—Reference Designation Index. Provides a cross-reference between the Reference Designation Number assigned to each item of electrical, electronics, or mechanical equipment and the part number for each such item. Reference designation numbers for each of the items of equipment are determined from the applicable section of the MIM.

USING THE IPB.—In order to derive maximum benefit from maintenance functions, certain records and reports must be compiled. Some of these reports and records require details concerning parts that have failed or that have been replaced for any reason. These details are available from the IPB. The procedures for locating the information depend on what is known about the part and what data

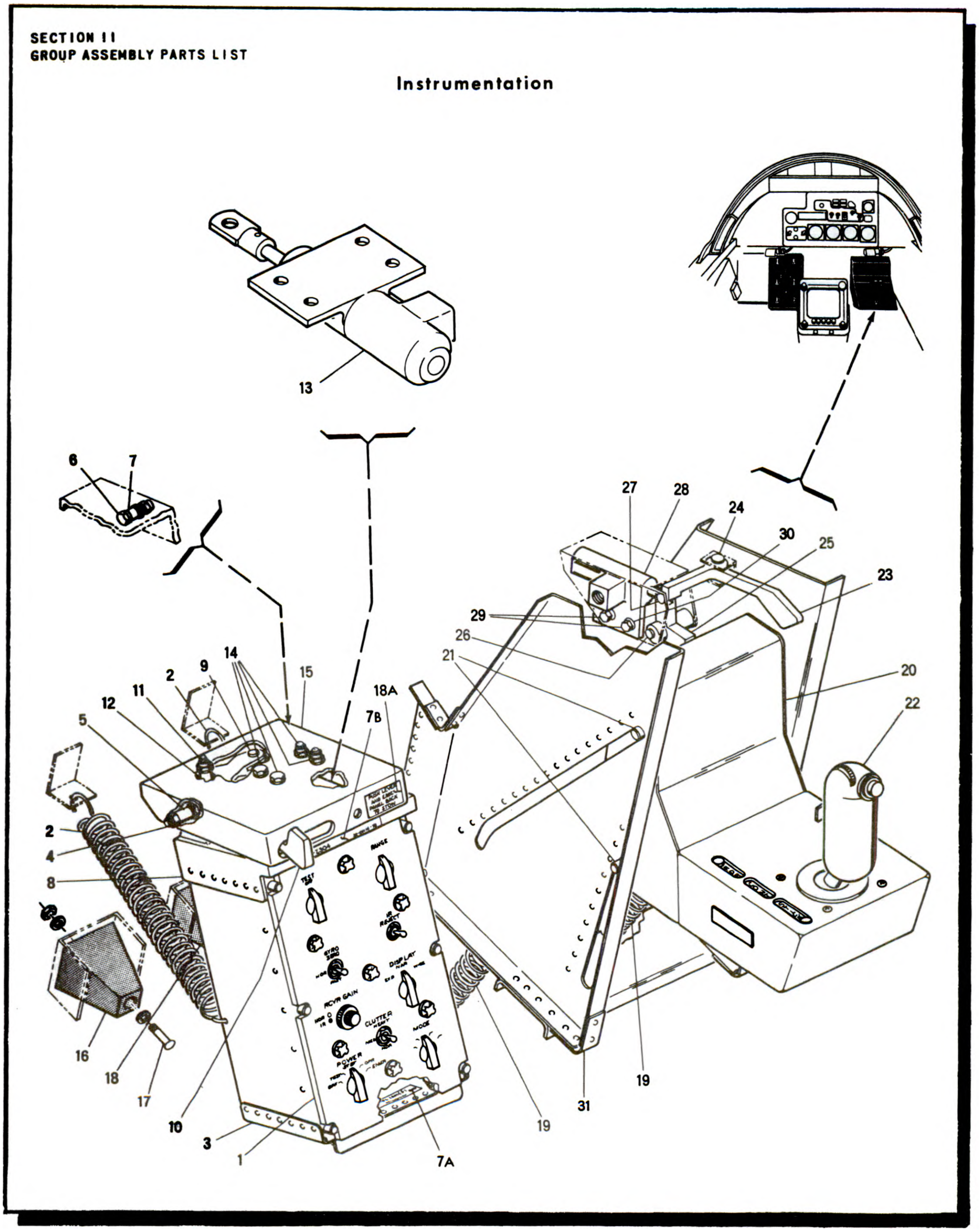


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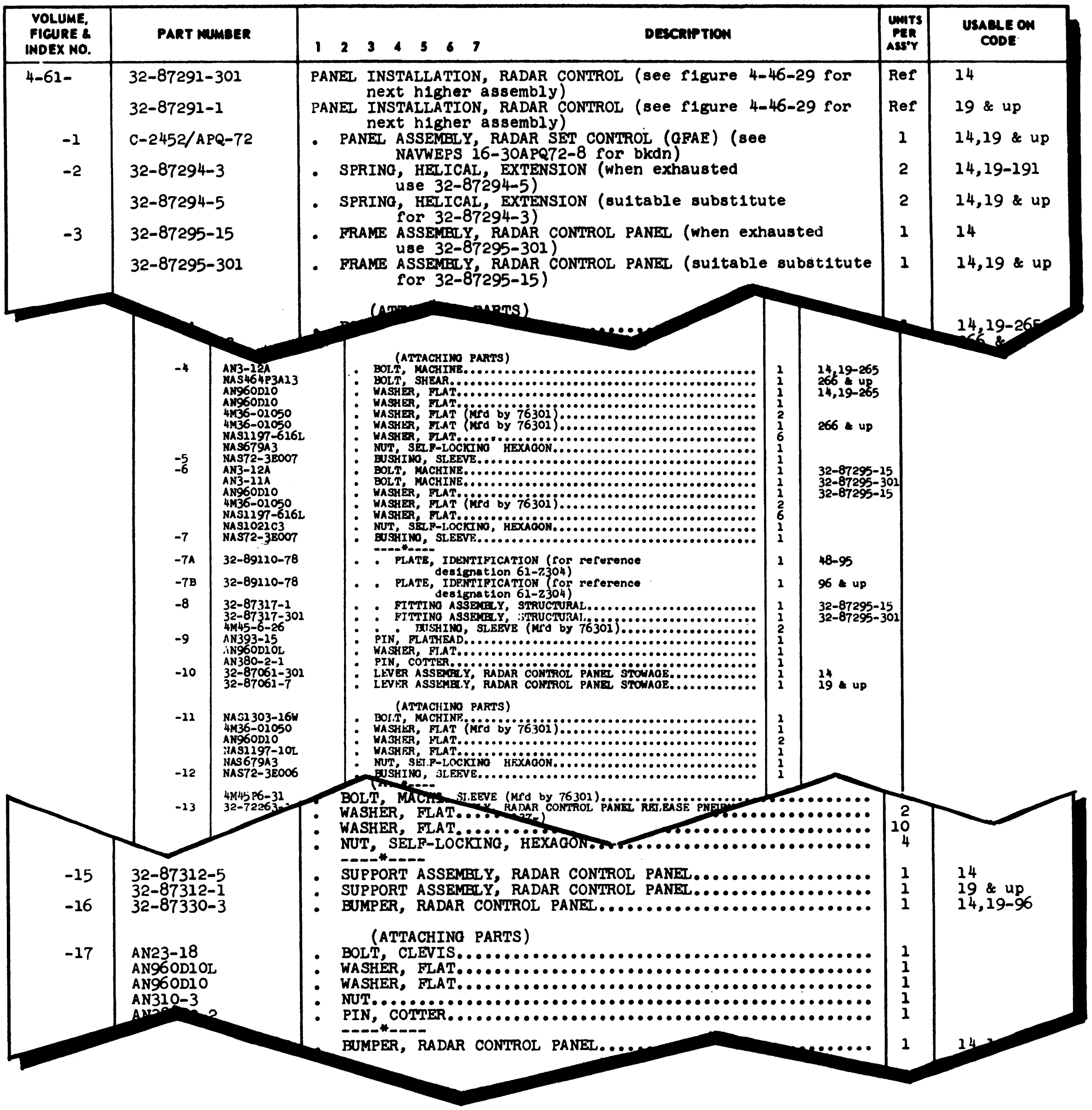
Figure 4-1.—IPB sample figure, radar control panel installation and stick assembly.



VOLUME, FIGURE & INDEX NO.	PART NUMBER	DESCRIPTION 1 2 3 4 5 6 7	UNITS PER ASS'Y	USABLE ON CODE
4-61-	32-87291-301	PANEL INSTALLATION, RADAR CONTROL (see figure 4-46-29 for next higher assembly)	Ref	14
	32-87291-1	PANEL INSTALLATION, RADAR CONTROL (see figure 4-46-29 for next higher assembly)	Ref	19 & up
-1	C-2452/APQ-72	. PANEL ASSEMBLY, RADAR SET CONTROL (GFAE) (see NAVWEPS 16-30APQ72-8 for bkdn)	1	14,19 & up
-2	32-87294-3	. SPRING, HELICAL, EXTENSION (when exhausted use 32-87294-5)	2	14,19-191
	32-87294-5	. SPRING, HELICAL, EXTENSION (suitable substitute for 32-87294-3)	2	14,19 & up
-3	32-87295-15	. FRAME ASSEMBLY, RADAR CONTROL PANEL (when exhausted use 32-87295-301)	1	14
	32-87295-301	. FRAME ASSEMBLY, RADAR CONTROL PANEL (suitable substitute for 32-87295-15)	1	14,19 & up
		(ATTACHING PARTS)		
-4	AN3-12A	. BOLT, MACHINE	1	14,19-265
	NAS464P3A13	. BOLT, SHEAR	1	266 & up
	AN960D10	. WASHER, FLAT	1	14,19-265
	AN960D10	. WASHER, FLAT	1	
	4M36-01050	. WASHER, FLAT (Mfd by 76301)	2	
	4M36-01050	. WASHER, FLAT (Mfd by 76301)	1	266 & up
	NAS1197-616L	. WASHER, FLAT	6	
	NAS679A3	. NUT, SELF-LOCKING HEXAGON	1	
-5	NAS72-3E007	. BUSHING, SLEEVE	1	
-6	AN3-12A	. BOLT, MACHINE	1	32-87295-15
	AN3-11A	. BOLT, MACHINE	1	32-87295-301
	AN960D10	. WASHER, FLAT	1	32-87295-15
	4M36-01050	. WASHER, FLAT (Mfd by 76301)	2	
	NAS1197-616L	. WASHER, FLAT	6	
	NAS1021C3	. NUT, SELF-LOCKING, HEXAGON	1	
-7	NAS72-3E007	. BUSHING, SLEEVE	1	
		----*----		
-7A	32-89110-78	. . PLATE, IDENTIFICATION (for reference designation 61-Z304)	1	48-95
-7B	32-89110-78	. . PLATE, IDENTIFICATION (for reference designation 61-Z304)	1	96 & up
-8	32-87317-1	. . FITTING ASSEMBLY, STRUCTURAL	1	32-87295-15
	32-87317-301	. . FITTING ASSEMBLY, STRUCTURAL	1	32-87295-301
	4M45-6-26	. . . BUSHING, SLEEVE (Mfd by 76301)	2	
-9	AN393-15	. PIN, FLATHEAD	1	
	AN960D10L	. WASHER, FLAT	1	
	AN380-2-1	. PIN, COTTER	1	
-10	32-87061-301	. LEVER ASSEMBLY, RADAR CONTROL PANEL STOWAGE	1	14
	32-87061-7	. LEVER ASSEMBLY, RADAR CONTROL PANEL STOWAGE	1	19 & up
		(ATTACHING PARTS)		
-11	NAS1303-16W	. BOLT, MACHINE	1	
	4M36-01050	. WASHER, FLAT (Mfd by 76301)	1	
	AN960D10	. WASHER, FLAT	2	
	NAS1197-10L	. WASHER, FLAT	1	
	NAS679A3	. NUT, SELF-LOCKING HEXAGON	1	
-12	NAS72-3E006	. BUSHING, SLEEVE	1	
	4M45P6-31	. BUSHING, SLEEVE (Mfd by 76301)		
-13	32-72263	. ASSEMBLY, RADAR CONTROL PANEL RELEASE PNEU		
		. BOLT, MACH		
		. WASHER, FLAT	2	
		. WASHER, FLAT	10	
		. NUT, SELF-LOCKING, HEXAGON	4	
		----*----		
-15	32-87312-5	. SUPPORT ASSEMBLY, RADAR CONTROL PANEL	1	14
	32-87312-1	. SUPPORT ASSEMBLY, RADAR CONTROL PANEL	1	19 & up
-16	32-87330-3	. BUMPER, RADAR CONTROL PANEL	1	14,19-96
		(ATTACHING PARTS)		
-17	AN23-18	. BOLT, CLEVIS	1	
	AN960D10L	. WASHER, FLAT	1	
	AN960D10	. WASHER, FLAT	1	
	AN310-3	. NUT	1	
	AN	. PIN, COTTER	1	
		----*----		
		BUMPER, RADAR CONTROL PANEL	1	14

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Figure 4-2.—IPB sample.

is required, as shown in the following discussion:

1. When the part number is not known, determine the function and application of the part. Turn to the Table of Contents of the IPB volume containing the affected equipment or system and select the title that seems most appropriate. Note the illustration page number. Turn to the page indicated and locate the desired part on the illustration. From the illustration, obtain the index (callout) number assigned to the part. Refer to the accompanying description for specific information regarding the part. (If the Federal Stock Number (FSN) is desired, next refer to the Index volume of the IPB. Locate the part number and note the FSN.)

2. When only the part number is known, refer to the Numerical Index. Locate the part number and note the figure and index number assigned to the part. Turn to the figure indicated, and locate the referenced index number. If a pictorial representation of the part or its location is desired, refer to the same index number on the accompanying illustration. If the FSN is desired, it may be determined directly from the Index volume by locating the part number.
3. When only the reference designation is known, refer to the Reference Designation Index. Locate the reference designation and note the figure and index number and the part number assigned. Turn to the figure indicated and locate the index number. If a pictorial representation of the part or its location is desired, refer to the index number shown on the accompanying illustration.

Periodic Maintenance Requirements Manual (PMRM)

Periodic maintenance requirements for a particular model aircraft are contained in the -6 series of publications for that model aircraft. The series includes (in addition to the Periodic Maintenance Requirements Manual) the cards and charts used to plan and control the progress of work in scheduled maintenance actions. They provide step by step procedures for performing the minimum inspections required for each type of scheduled maintenance action.

EQUIPMENT MANUALS

Most items of electronics equipment or test equipment commonly used in naval aviation are covered by a manual or a series of manuals. These manuals are usually prepared by the contractor and distributed by NASC. Standardization has not progressed to the same extent as it has in the aircraft manuals; however, some generalizations hold true for most manuals of this group.

NavAir 08- (Series)

Manuals of this category usually apply to older equipments which are still in use. (One very important exception is the NAESU Digest, NavAir 08-1-503, discussed later in this chapter.) The 08-series is at present undergoing a complete reorganization and is being combined with the 16- series for electronics equipment. In the issue of the NavSup Publication 2002 used in preparing this course, the 08-entry refers the user to the 16- entry. In the 16- listing, the 08- manuals are listed preceding the 16- manuals.

NavAir 16- (Series)

Manuals of this series are identified by a numbering system similar to that used with the aircraft manuals, consisting of a three-part designation following a prefix. The prefix and the Part I serve the same purpose and follow the same rules as outlined in the preceding section. Parts II and III are not completely standardized except for subsections 30 and 35. The subdivisions of the 16- series are listed in table 4-2.

Table 4-2.—NavAir 16- (Series) breakdown.

Subseries	Classification
1	General
5Q	Radio
5S	Radar
30	Joint Nomenclature Radio Equipment
35	Joint Nomenclature Radio Components
40	Signal Corps Nomenclature Equipment
45	Commercial British and Navy Radio Equipment
50	Automatic & Semiautomatic Electronic Checkout Equipment
55	Radio, Radar, Electronic, and Spare Parts Lists

GENERAL.—NavAir 16-1 (Series) manuals include several publications of many types, the contents of which do not permit inclusion in any other subseries. They include manuals pertaining to general maintenance practices, training manuals, design guidance data, etc. Some of these manuals have been individually referenced in this chapter; some others are referenced in chapters throughout the course. A complete listing is available in the current indexes of publications.

RADIO AND RADAR.—Manuals of the 5Q and 5S subseries pertain to older equipments, and the manuals do not conform to present standardization format. They include miscellaneous operation and maintenance data for radio and radar equipments.

JOINT NOMENCLATURE RADIO EQUIPMENT.—Manuals of this subseries normally appear in the standard format. One example of a manual in this subseries of interest to the AQ would be IPB for the Radar Set AN/APQ-83. The publication number of this manual is NW 16-30APQ83-4. Part II of the identifying designator specifies the equipment to which the manual applies; Part III specifies the type manual. Although Part III is not completely standardized, the number refers to the following type manuals:

Operation Instructions
Service Instructions
Overhaul Instructions
Illustrated Parts Breakdown

Many smaller and less complicated equipments combine two or more of these manuals into one volume, but each of the above manuals is discussed separately in this chapter.

Table 4-3.—NavAir 11- (Series) breakdown.

Series subdivisions	Classification
11-1	General
11-5	Bombing equipment and accessories
11-10	Gun mounts
11-15	Pyrotechnics
11-20	Synchronizers
11-45	Power gun turrets
11-55	Tow targets
11-60	Automatic flight control equipment
11-70	Armament control systems and related components
11-75	Missiles and related equipment
11-80	Mine carrying equipment
11N-	Armament, nuclear

NavAir 11- (Series)

The manuals in this series are concerned with the overall subject of Aircraft Armament, and are broken down into subdivisions. These subdivisions are shown in table 4-3. One subdivision of this series which is of importance to the AQ is the 11-70 subdivision (Armament Control Systems and related components). An example is the Service Instructions Manual for the Armament Control System AN/AWG-4 installed in the F-8E. The publication number for this manual is NW 11-70HD-502.

Operation Instruction Manual

Operation Instruction Manuals cover the operation of specific equipments and the necessary checks and adjustments required for optimum performance. These instructions are written from the equipment operator's viewpoint and do not include all data vital to the maintenance technician.

Service Instruction Manual

The Service Instruction Manual contains information on maintenance and usage of specific equipment. It provides instructions for alining, maintaining, troubleshooting, and repairing the equipment, as well as concise tabular data on fuses, power drain, number of units, etc. Because of the quantity and complexity of the material involved, the manual is divided into several sections.

Section I, Description and Leading Particulars, gives a description of the equipment and the general principles of its operation. Included in the section is information on the interchangeability of components and any special electrical or mechanical characteristics of the system or components.

Section II, Special Test Equipment and Special Tools, lists all necessary special test equipment and tools (including test racks) which are used for complete bench testing of the system or the components. Any instructions necessary for modifying the test equipment for special use or for the fabrication of a special test harness are also found in this section.

Section III, Preparation for Use and Reshipment, is divided systematically, showing the method by which the equipment should be handled from the time it is received until it is ready for use by the operator. The section contains general information on uncrating and assembling the equipment on the test bench or in the aircraft, removing it from the aircraft, and recrating it for shipment. Detailed descriptions of cable fabrication and the connections of cables to the components are also included. Applicable data on any checks and adjustments required during installation of the equipment is found in this section.

Section IV, Theory of Operation, presents a general description of the equipment first, and this is followed by the detail explanations of the individual circuits. The general description is usually given from the viewpoint of circuit development and block diagrams are used to trace the development path. The function of each unit is explained, as well as its relationship to other units in the equipment.

Section V, Organizational and Operational Maintenance, provides the instructions essential for the maintenance of the equipment by organizational maintenance personnel, and indicates the level of maintenance activities designated to perform it. Included are the preoperational and daily inspections and tests, the bench-test procedures, and the troubleshooting methods to be used by these activities. Each performance procedure in this section includes instructions essential for the proper use of test equipment in diagnosing a trouble within a specific equipment.

Section VI, Field Maintenance, includes the instructions required for servicing the equipment at the field maintenance levels. In addition to alinement and parts removal procedures, information is given for checking component functions by means of performance checks. Also contained in this section are systematic trouble isolation procedures which assist in localizing a defective part or component to a circuit or group of circuits, depending upon the nature of the equipment. Each performance procedure in this section includes instructions essential for the proper use of the test equipment in diagnosing a trouble within a specific equipment.

Section VII, Diagrams, contain all the diagrams necessary for the maintenance and interconnection of the equipment. It includes complete block, schematic, and wiring diagrams of the equipment and of components (for use in trouble analysis). Voltage, resistance, and cabling charts of the equipment are also included. Obviously, the use of Section VII demands clear understanding of diagram interpretation.

Section VIII, Difference Data Sheets, may be added (when required) to provide information on improved or modified models of the original equipment.

Overhaul Instruction Manual

The Overhaul Instruction Manual provides detailed information for overhauling the electronics equipment and/or component. This includes such procedures as disassembly, cleaning, repair, recalibration, testing, and any other steps necessary for complete overhaul. The manual also includes a tabulated list of test equipment recommended for overhaul. It is issued primarily to overhaul activities because the nature of the work described is usually beyond the capacities and facilities of field maintenance activities.

Illustrated Parts Breakdown

The Illustrated Parts Breakdown for equipments is similar in format, purpose, and usage to the IPB for aircraft as previously discussed.

Combined Manuals

Frequently, especially for components and small items of electronics test equipment, two or more of the above manuals are combined into a single publication. In most of these cases, the general material content may be determined from the title, but the arrangement of sections within the manual will vary with the individual publication.

REVISIONS

In an effort to provide maintenance activities with the latest and most accurate information possible, the Naval Air Systems Command has instituted a program of continuous review and frequent revision of technical publications and manuals. These revisions are classed as formal or informal.

FORMAL revisions are printed, and are distributed as a new manual or as a partial replacement on a page-by-page basis. Formal revisions are reflected in the cumulative supplement to the NavSup publications index. INFORMAL revisions include changes authorized by other means such as messages, notices, letters, or periodicals. They are normally "pen-and-ink" type changes.

Incorporation of Revised Material

When making a pen-and-ink change to any official publication or directive, be sure to record the source of the corrected material or the authority for the change. In this manner, subsequent users of the document will know that the change is official and also where to look for additional details. Eliminating the confusion which results from too much information, some of which may be incorrect, will make the document much more valuable as a tool for maintenance.

When making a substitute page type revision to a manual, be sure to double check that all instructions forwarded with the change copy are complied with. These instructions normally include the removal of certain pages, and substitution of other pages in their place. Be sure that all canceled pages are removed and disposed of in the proper manner, and that all pages not canceled are retained in their proper sequence.

When making a revision of any type to any official document, record the data concerning the number of the change, authority, date of the incorporation of the revision, and the name or initials of the person making the incorporation. In most technical manuals, a special page is included for this purpose.

Reporting of Errors in Manuals

As a part of the program to improve the quality and accuracy of its technical manuals, the Naval Air Systems Command has initiated a program for encouraging users to report errors and discrepancies. At the time of writing, the program applies only to certain specified types of manuals, but it is planned to expand the program to include all technical manuals. The basic reporting document is the Unsatisfactory Material/Condition Report (UR).

SPECIFICATIONS

A specification is a minutely detailed description or designation of the characteristics, particulars, values, or tolerances which must be met by a product or process.

The technician is concerned with specifications every time he performs an inspection, calibration, adjustment, operation, or repair on any unit of electronic equipment. In order for the equipment to fulfill its purpose, it must operate in a specified manner—it must meet definite requirements of sensitivity, power output, timing, phase, frequency, signal characteristics, etc. Specifications for a particular unit are found in the operation and inspection manuals and procedures for the applicable aircraft or equipment.

Failure of an item of electronics equipment to meet its specifications will prevent the aircraft from performing at its maximum capability. This condition calls for the removal, adjustment, repair, or calibration of the defective unit. To insure that all equipments are operating within the tolerances allowed in the specifications, operational inspections must be performed at frequent intervals, and in a precise and thorough manner.

Federal Specifications

Federal specifications are prepared under the direction of and promulgated by the Administrator of General Services, and apply to items in general usage by government agencies.

Military Specifications

Military specifications cover materials, products, or services used predominantly by military activities, but which may be used by other federal agencies. These specifications are issued and promulgated by the Office of Standardization, Defense Supply Agencies.

Standards

A standard is a reference or a sample set up or established by competent authority to be used as a guide for comparison or evaluation.

The technician is constantly involved with standards. Every time he measures voltages in a circuit, he is comparing the potentials in that particular circuit with the standard volt. Every time he reads a schematic or block diagram, he recognizes the standard symbols used in the drawing. Every time he reads an explanation of the theory of operation for a circuit, he recognizes and understands the meaning of standard terms. When he replaces a defective resistor or capacitor, he installs a standard item.

Standards make possible the rapid, clear, and concise communication of facts, ideas, and information; without standards, modern technology would be impossible.

FEDERAL STANDARDS.—Federal standards are documents that establish engineering and technical limitations for items, materials, processes, methods, designs, and engineering practices. These documents are for general use by governmental agencies.

MILITARY STANDARDS.—Military standards are documents that establish engineering and technical limitations and applications for items, materials, processes, methods, designs, and engineering practices. These documents are intended primarily for use by agencies of the Department of Defense.

INSTRUCTIONS AND NOTICES

The Navy Directives System is used throughout the Navy for the issuance of directive type releases. Some of these prescribe policy, organization and methods, or procedures; others contain general information. The directives system provides a uniform plan for issuing and maintaining directives; conformance is required of all bureaus, offices, activities, and commands of the Navy. Two types of releases are authorized under the plan—Instructions and Notices.

Information pertaining to action of a continuing nature is contained in Instructions. An Instruction has permanent reference value and remains in effect until the originator supersedes or cancels it. Notices contain information pertaining to action of a onetime nature. A Notice does not have permanent reference value and contains provisions for its own cancellation.

For purposes of identification and accurate filing, all directives can be recognized by the originator's authorized abbreviation; the type of release (whether an Instruction or Notice); a subject classification number; and, in the case of Instructions only, a consecutive number. (Because of their temporary nature, the consecutive number is not assigned to Notices.) This information is assigned by the originator and is placed on each page of the release.

The manner of numbering and identifying directives can be better understood by considering a typical identifier:

SECNAV	INST	5215.1A
(a)	(b)	(c) (d)

(a) The authorized abbreviation of the originator of the directive.

(b) The type of release (in this case an Instruction).

(c) The subject number of the (directive obtained from the Table of Subject Classification Numbers).

(d) The consecutive number (found only on Instructions). An originator would assign consecutive numbers to those consecutive instructions with the same subject classification number. In the example above, the subject classification number 5215 concerns "Issuance Systems." If the originator, SecNav, issued additional Instructions dealing with issuance systems, they would be assigned the numbers 5215.2, 5215.3, 5215.4, etc. The letter A indicates that this is the first reissue of the same basic directive.

Subject classification numbers are listed in the Table of Subject Classification Numbers found in SecNav Instruction P5210.11 (Series). This table contains a numerical and alphabetical listing of numbers with their related subjects, and has reference value when information or instructions of a particular nature are desired. This Instruction contains all necessary information concerning the use and procedures of the Navy Directives System.

Instructions and Notices promulgated by the Naval Air Systems Command are preceded by the prefix NavAir.

LETTER TYPE TECHNICAL DIRECTIVES (CHANGES AND BULLETINS)

BuWeps Instruction 5215.8 established a system to promote uniformity in technical directives. This system is limited to instructions of a technical nature which are not contained in technical manuals and which cannot be satisfactorily incorporated as revisions to the manuals. NavSup Publication 2002, Cognizance Symbol I, Section VIII, Part D, together with its latest cumulative supplement, provides a checkoff list for all current technical aeronautic letter publications.

A CHANGE is a technical directive containing instructions and directions to accomplish a material change, modification, repositioning, or alteration in the physical appearance of an aircraft or equipment or the installation of different parts in subassemblies, assemblies, or components in aircraft or equipment.

A BULLETIN is a technical directive containing instructions and directions to accomplish inspections, calibrations, tests and adjustments, or additional instructions on standard rework, methods, limitations, and procedures which do not fall within the change definition.

A GENERAL BULLETIN may be used in instances where the instructions and directions apply to a number of different powerplants, airframes, etc.

An INTERIM CHANGE or an INTERIM BULLETIN is a change or bulletin directive in message form which defines the action to be taken to correct a safety or operational condition which embodies risks considered to be in need of immediate correction. Interim directives may or may not contain the final solution to the problem. Interim directives are issued only when the action classification (discussed below) is Immediate or Urgent.

Action Classification

The action classification and compliance requirements for completing the directed action are of major concern and importance. In establishing time limits, the originator has considered the type and seriousness of the deficiency, operational employment and environmental conditions affecting the deficiency, prior to accomplishment of other changes, and special tools or facilities required.

IMMEDIATE ACTION.—This type directive is concerned with problems involving safety, which would probably result in fatal or serious injury to personnel, or destruction of (or extensive damage to) property, unless corrected within extremely narrow time limits. Immediate Action directives involve the immediate discontinued use of the aircraft, engine, or equipment in the operational employment under which the adverse safety condition exists. If continued use will not involve the affected component or system in either normal or emergency situations, compliance may be deferred until (but no later than) the next periodic inspection for aircraft and engines, and no later than 6 months from date of issue for equipments.

URGENT ACTION.—A directive of this type also indicates a problem in safety conditions which could result in personal injury or property damage unless corrected. The major difference is that time limits are not quite so close as with Immediate Action directives, but are still narrow. Operating restrictions may or may not be imposed. (This classification may also be used for mission capability changes when operational and deployment commitments are considered of overriding importance.)

Interim directives classified Urgent Action require incorporation within 60 days from date of issue in those aircraft, engines, or equipments employed under conditions in which the hazard exists. If continued operation will not involve use of the affected component under either normal or emergency situations, action may be deferred up to 180 days from date of issue.

Formal directives classified Urgent Action require incorporation not later than the next Progressive Aircraft Rework (PAR) period or overhaul for aircraft and engines, and 18 months from date of issue for equipments.

ROUTINE ACTION.—These directives indicate conditions which, if uncorrected, could eventually result in personnel injury or property damage, or could have an adverse effect on operation, maintenance, or support functions. Although a hazard may exist, the situation is not considered to be critical; therefore, action may be deferred not more than one PAR or overhaul for aircraft and engines, and 18 months from date of issue for equipments.

Noncritical changes requiring the facilities of a Naval Air Rework Facility could seriously interfere with operational or deployment commitments. In this event, the change may be deferred by the controlling custodian until the next succeeding PAR or overhaul.

Title

Changes and bulletins are issued under title subjects—Airframe, Powerplant, Avionics, Accessory, Support Equipment, Aviation Armament, Air Crew System, Photographic, Clothing & Survival Equipment, and Propeller.

Numbering

The number is assigned separately for each type directive and for each title subject, in numerical sequence by date of approval (not necessarily the date of issue). Interim changes and bulletins are numbered in sequence along with formal directives; formal directives issued to supersede interims retain the same sequence number.

Occasionally directives require amendment or revision. A REVISION is a completely new edition of an existing publication, and bears the words "Rev. A" or "Rev. B" as appropriate.

An AMENDMENT makes a minor change or addition to the basic directive, and is indicated by "Amendment 1" following the basic title.

Some changes are intended to be installed in stages, or by different level maintenance activities. These changes are issued as "Part I" and "Part II" of the basic directive.

Format

Although there are some slight variations in detail, all letter type technical publications conform generally to a standardized format. Only a few of the topics covered in the directive warrant discussion in this course. They are as follows:

1. Publications affected. Lists the publications which should be revised as a result of incorporation of the directive.
2. Application. Identifies the specific aircraft, engines, or equipment to which the directive applies.
3. Supply Data. Presents detailed information concerning all material and supply transactions involved in support of the directed action.
4. Detailed instructions. For the maintenance technician, this is the most important part of the directive. It presents the detailed step by step procedures to be followed in accomplishing the directed action.
5. Identification. Gives instructions for marking the unit upon completion of the action, for easy identification of those units which have undergone modification.
6. Log entry. Indicates the entry, if any, to be made on the applicable logbook.

Obsolescent Types

Many directives which were issued prior to the standardization of the directives system are still effective. These include Aviation Circular Letters, Technical Orders, Technical Notes, Aircraft Changes and Bulletins, Electronic Material Changes, and Electronic Material Bulletins. Although these directives are no longer being issued, those which have not been canceled or superseded are included in the latest edition of the NavSup 2002.

Local Action

Upon receipt of a letter type technical directive, either formal or interim, the directive must be screened by the maintenance activity to determine its applicability to units or aircraft maintained by that activity. If local compliance is required, a local maintenance instruction is prepared to direct compliance by shop personnel. This local instruction provides a ready reference to determine the status of action based on that directive in the activity, and provides a record of which units have been processed.

PERIODICALS

Many periodicals of interest to the AQ are published and issued by naval activities and commands. A few of the most important are discussed in the following paragraphs.

NAESU Digest

Each month the Naval Aviation Engineering Service Unit (NAESU) prepares and publishes two editions of the Digest of U.S. Naval Aviation Weapons Systems. The Aeronautical Edition is primarily for the mechanical rates, although the technician should review it. The edition of prime concern to the technician is the Avionics Edition. This Digest contains information on electrical and electronics equipment relative to operation, maintenance, installation, and supply. This is an excellent source of information dealing with new equipment and new ideas for the older equipment. It gives the latest procedures (developed by NAESU and other activities) for speeding the testing, calibration, and alinement of equipment. In general, it is as the name suggests—a "digest" of all the latest information pertaining to work in electronics. It should be on the "must read" list for all hands, and always available for ready reference.

Approach

Approach, The Naval Aviation Safety Review, is published monthly by the U.S. Naval Safety Center. It is distributed to naval aeronautical organizations on the basis of one copy for each ten personnel assigned. It presents the most accurate information currently available on the subject of aviation accident prevention. It is an unofficial publication, and its contents are not to be considered as regulations, orders, or directives. It should, however, be read each month by all aviation personnel.

Naval Aviation News

Naval Aviation News is published monthly by the Chief of Naval Operations and the Naval Air Systems Command. Its purpose is to disseminate information on aircraft, aviation training and operations, and other aeronautical matters.

This publication should be read each month by all naval aviation personnel.

All Hands

ALL HANDS, NavPers-0 Series, the Bureau of Naval Personnel Career Publication, is published monthly by the Bureau of Naval Personnel for the information and interest of the naval service as a whole. It is not an official publication in the sense of constituting authority for action based on information contained therein; nor is it a statement of official policy. However, it is an important publication in that it contains information vital to naval personnel.

Distribution of All Hands is automatic to each activity, and is based on one copy for each ten personnel assigned. It should be read every month by all personnel.

DRAWINGS AND SCHEMATICS

Nearly all technical manuals make extensive use of drawings and diagrams. The technician uses these figures in nearly every phase of his work—the location and identification of units and components, troubleshooting, signal and/or circuit tracing, installation, calibration and adjustment, testing, operation, and evaluation. He also uses these figures in the study of operating principles of circuits and equipments.

No one particular type illustration is suitable for all applications; therefore, many different types are required. Several of the different types are discussed in the following paragraphs. Each type has its own advantages and disadvantages.

NOTE: Blueprint Reading and Sketching, NavPers 10077-B, provides many details concerning the construction of illustrations and drawings. Review of that manual should be made prior to continuing the study of this chapter.

ILLUSTRATIONS

Illustrations are commonly used to present visually the idea of a text. To this end, illustrations are used in many forms. A few of these are the photograph, line drawing, shaded sketch, cutaway view, blueprint, etc. Some of the more common illustrations are discussed briefly in this chapter.

Pictorial

Pictorial illustrations normally indicate physical appearance. They may present details concerning the location, size, construction, physical relationships of size and location, or parts arrangement. They appear throughout manuals of all types, and are useful for locating and identifying systems, equipments, components, or parts. They are used in connection with installation, inspection, servicing, operation, adjustment, calibration, troubleshooting, and repair functions.

Pictorial illustrations may be accurately detailed representations, or they may be merely generalized indications, depending on their purpose. They may be photographs, halftone or shaded sketches, or line drawings.

Cutaway View

A cutaway view is an illustration used to show some detail of construction which would be extremely difficult or impossible to show by conventional pictorial views. It is often used in connection with discussions of physical construction and the operation of mechanical devices. It is frequently used in assembly diagrams and in construction details.

Location and Dimension

Location diagrams are used to show physical position relationships, and may or may not be sufficiently detailed to show physical appearance. They are primarily useful for familiarization, and are commonly used in Flight Manuals, in the General Information and Servicing section of the Maintenance Instructions Manuals (MIM's), in the Illustrated Parts Breakdown Manual (IPB), and in the Operation and Maintenance Instructions for equipments. (These manuals are described later in this chapter.)

Dimension diagrams denote physical size and distance. They are useful in planning the layout of bench stations, making equipment installations, or packing materials for reshipment. They are frequently used in the general information sections of technical manuals, and in those sections devoted to familiarization, installation, and shipment. They are also frequently found in change type technical directives.

Location and/or dimension diagrams may be combined with other type illustrations, thus providing additional details without increasing the number of illustrations.

Assembly Diagrams

Assembly diagrams, as the name implies, provide details of construction which are useful in assembling parts into a unit. They are also useful in explaining the operation of mechanical or electromechanical devices.

BLOCK DIAGRAMS

Block diagrams are used to present a generalized explanation of overall functional operation, and do not show physical shape, size or location. They range from very simple to very complex, depending on the type equipment, the quantity and quality of details to be covered, and the purpose for which the information is included. They are found in nearly all manuals dealing with basic or detailed theory of operation, whether of relatively simple subassemblies or of very large and complex systems. The more complex the equipment, the more probable the need for block diagrams.

Many block diagrams are used in connection with electromechanical devices, as well as with electrical or mechanical systems. Proper use of this type diagram helps increase understanding of functional relationships and operation.

Symbols

Since block diagrams are used mainly to provide a general analysis of functional operation, symbols are generally used to represent individual circuits or functional components. In order to make maximum use of block diagrams, it is essential to recognize the symbols and to understand their meanings and limitations. Appendix II of this manual contains many of the common symbols found on block diagrams. Several block diagrams are included in this course.

Signal Flow

One special type of block diagram is called the signal flow diagram or signal flow chart. It is usually used in connection with overall operation of complicated systems such as fire control computers, ASW systems, aircraft control or power distribution systems, or search or navigation radar systems. It includes all features normally associated with block diagrams; and in addition, it includes considerable detail regarding signal paths, signal waveshape, timing sequence and relationships, magnitudes of potentials or signals, frequencies, etc.

WIRING DIAGRAMS

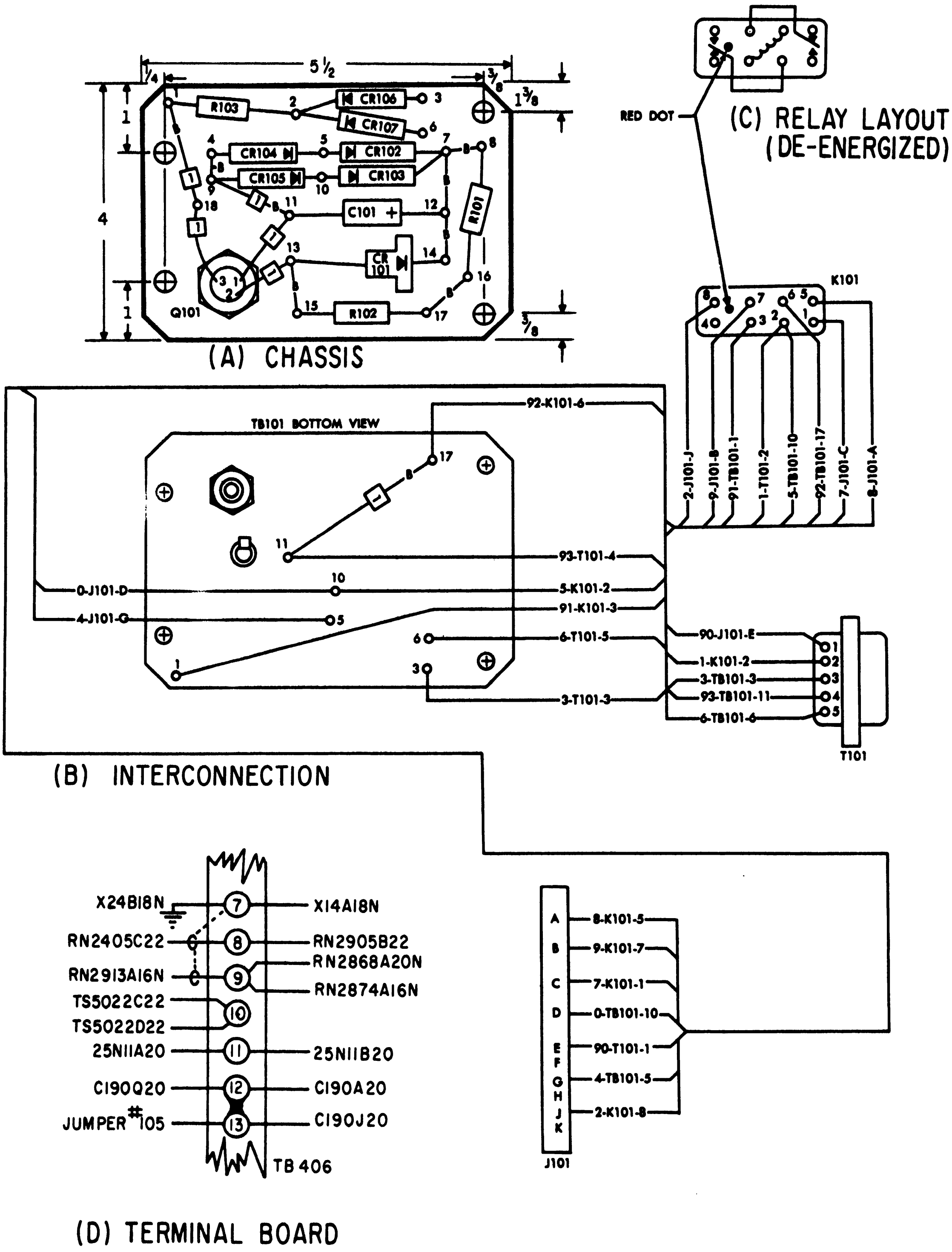
The wiring diagram presents detailed circuitry information concerning electrical and electronics systems. A master wiring diagram is a single diagram that shows all the wiring in a complete system or in an aircraft. In most cases, this diagram would prove to be too large to be usable; it is normally broken down into logical functional sections, each of which may be further subdivided into circuit diagrams. By breaking a system into individual circuit diagrams, each individual circuit may be presented in greater detail. The increased detail provides for easier circuit tracing, testing, and maintenance.

Wiring diagrams fall into two basic classes—chassis wiring and interconnecting diagrams—each with specific purposes and many variations in appearance (depending on application). Wiring diagrams are not generally used for discussions of theory of operation of specific circuits.

Figure 4-3 (A) is an example of one type chassis wiring diagram commonly used. This drawing shows the physical layout of the unit, and all component parts and interconnecting tie points are shown. Each indicated part is identified by reference designation number, thus facilitating use of the IPB to determine values and other data. (The values of resistors, capacitors, or other components are normally not indicated on wiring diagrams.) The polarity of semiconductor diodes and of the polarized capacitor is shown. The lead numbers for the transistor (Q101) are used for convenience.

Since this specific diagram shows physical layout and dimensioning details for mounting holes, it could be used as an assembly drawing and also as an installation drawing.

Figure 4-3 (B) shows the reverse side of the same mounting board, together with the wiring interconnections to other components. Actual



AT.

Figure 4-3.—Wiring diagrams. (A) Chassis wiring; (B) interconnection wiring; (C) sealed component parts layout; (D) terminal board connections.

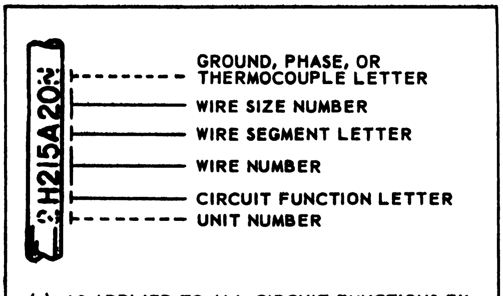
positioning of circuit components is not indicated, and wire bundles are represented as single lines with the separate wires entering at an angle. (The angle indicates the direction to follow in tracing the circuit to locate the other end of the wire.)

The wire identification coding on this diagram consists of a three-part designation. The first part is a number representing the color code of the wire in accordance with Military Specification MIL-W-76A. (Many other chassis wiring diagrams designate color coding by abbreviations of the actual colors.) The second is the reference part designation number of the item to which the wire is connected. The last is the designation of the specific terminal to which connection is made.

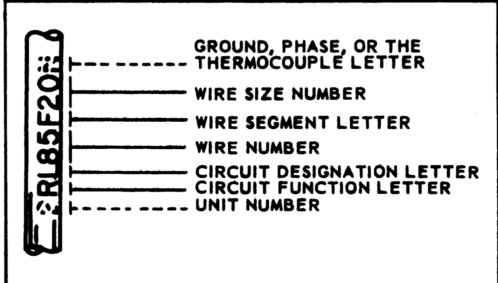
Figure 4-3 (C), while not a wiring diagram, illustrates a method commonly used to show some functional aspect of sealed or special components.

Figure 4-3 (D) illustrates several methods used to indicate connections at terminal strips. The details of wire identification coding used are discussed below.

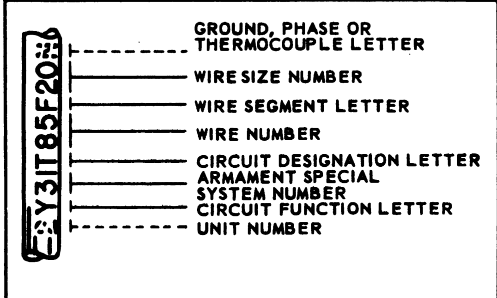
Wiring diagrams are normally the major content of the last volume of an MIM set, or the last section of most other maintenance manuals. This volume or section contains wiring diagrams for all electrical and electronic systems of the aircraft. The diagrams are prepared separately for each circuit and provide all data necessary to understand the construction of each circuit, to trace each circuit within the system to make continuity and resistance checks, and to perform specific troubleshooting on inoperative or malfunctioning circuits.



(a) AS APPLIED TO ALL CIRCUIT FUNCTIONS EXCEPT R, S, T, AND Y



(b) AS APPLIED ONLY TO CIRCUIT FUNCTIONS R, S, AND T


2Y31T85F20N
GROUND, PHASE OR THERMOCOUPLE LETTER
WIRE SIZE NUMBER
WIRE SEGMENT LETTER
WIRE NUMBER
CIRCUIT DESIGNATION LETTER
ARMAMENT SPECIAL SYSTEM NUMBER
CIRCUIT FUNCTION LETTER
UNIT NUMBER

(c) AS APPLIED ONLY TO CIRCUIT FUNCTION Y

AT.19

Figure 4-4.—Example of wire identification coding.

Aircraft Wire Identification Coding

To facilitate maintenance, all aircraft wiring is identified on the wiring diagrams exactly as marked in the aircraft. Identification of each wire is coded by a combination of letters and numbers imprinted on the wire at prescribed intervals along its entire run. Figure 4-4 and the accompanying discussion explain the code used in aircraft wiring installation. Complete details are to be found in the latest revision of MIL-W-5088.

The unit number (shown in dashed outline) is used only in those cases having more than one given unit installed in an identical manner in the same aircraft. The wiring concerned with the first such unit bears the prefix 1, and corresponding wires for the second unit have exactly the same designation except for the prefix 2, etc.

The circuit function letter identifies the basic function of the unit in accordance with table 4-4. Note that circuit function R, S, and T wiring may bear a second letter to designate the functional breakdown of the circuit.

Each wire within a given circuit function group is assigned a separate wire number. Wires that are segmented by the use of splices, plug and receptable connectors; terminal strip tie points, etc., are given a letter segment designation. Passage through a switch, relay,

Table 4-4.—Wiring circuit function code.

Circuit function letter	Circuits
A	Armament
B	Photographic
C	Control surface
D	Instrument
E	Engine instrument
F	Flight instrument
G	Landing gear
H	Heating, ventilating, and de-icing
J	Ignition
K	Engine control
L	Lighting
M	Miscellaneous
P	D-c power Wiring in the d-c power or power control system will be identified by the circuit function letter P.
Q	Fuel and oil
R	Radio (navigation and communication) RN—Navigation RP—Intercommunications RZ—Interphone, headphone
S	Radar SA—Altimeter SN—Navigation SQ—Track SR—Recorder SS—Search
T	Special electronic TE—Countermeasures TN—Navigation TR—Receivers TX—Television transmitters TZ—Computer
V	D-c power and d-c control wires for a-c systems will be identified by the circuit function letter V.
W	Warning and emergency
X	A-c power Wiring in the a-c power system will be identified by the circuit function letter X.
Y	Armament special systems

circuit breaker, etc., requires assignment of a new number.

Wire size numbers are omitted in the case of coaxial cables; they are replaced by a dash and coded designator when part of a thermocouple arrangement.

A suffix is added to designate the phase (or ground) in 3-phase a-c power wiring. In the case of thermocouples the suffix denotes the metal element involved.

Cable Construction

Cable construction diagrams present details concerning the fabrication and construction of cables. These details usually include designation of the type connectors or terminals, the identification of wires for each terminal, method of connecting wire to terminal, potting requirements, length of wires, lacing or sleeving specifications, and any other specifications or special considerations involved.

Cable Routing

Diagrams of major systems generally include an isometric shadow outline of the aircraft, showing the approximate location of equipment components and the physical routing of interconnecting cables. A cable, regardless of the number of conductors, is represented on an isometric wiring diagram as a single line; no attempt is made to show individual connections at equipment units or in connection boxes. An isometric type drawing thus shows at a glance a picture of the layout of the entire system.

SCHEMATICS

The major purpose of the schematic diagram is to establish the electrical operation of a particular system. It is not drawn to scale, and it shows none of the actual construction details of the system (such as a physical location within the aircraft, physical layout of components, wire routing, or any other physical detail) not essential to understanding circuit operation.

Schematic drawings differ from block diagrams in that they present more detail concerning each circuit. Whereas the block diagram deals with functional units of the system, the schematic diagram indicates each individual part which contributes to the functional operation of the circuit.

Simplified Schematics

In large or complex equipments, a complete schematic drawing may be too large for practical use. For this reason, most technical manuals present partial or simplified schematics for individual circuits or units.

Simplified schematics normally omit parts and connections which are not essential to understanding circuit operation. In studying or troubleshooting equipment, the technician frequently must make his own simplified drawings. In these cases he should include only those items that contribute to the purpose of the drawing, but he should take care to include all such items. In using the schematic drawings throughout this course (and those in technical manuals, textbooks, and other publications), many techniques for simplifying schematics will become apparent. Special attention should be paid to those techniques found useful by the individual maintenance man—they can be extremely important tools in his work.

Electromechanical Drawings

Electromechanical devices such as synchros, gyros, accelerometers, autotune systems, analog computing elements, etc., are quite common in avionics systems. For a complete understanding of these units, neither an electrical drawing nor a mechanical drawing would be adequate—and confusion could result from the use of two drawings. Therefore a combination type drawing, using some aspects of each component type, is used. These drawings are usually simplified both electrically and mechanically, and only those items essential to the operation are indicated on the drawing.

CHARTS AND TABLES

Charts and tables of many types are used throughout all types of technical publications to present factual data in a clear and concise form. As the terms are used in this discussion, a chart is used to present information in lists, pictures, tables, or diagrams; a table is one type of chart, and is used to present or list information in a very condensed form.

Tables prove valuable in instances when the same general type information is to be presented with respect to numerous items. The corresponding details for the items may be listed in columns, arranged so that reading across will present details regarding a specific item, while reading down will present a comparison of items with respect to a certain detail. One very common and useful table of this type is represented by the IPB listings discussed earlier in this chapter.

SECURITY OF CLASSIFIED MATERIAL

It is important that all personnel in the Naval Establishment be aware of (and comply with) regulations governing the use and safeguarding of classified material and information. The basic policy governing security is established and detailed in the Department of the Navy Security Manual for Classified Material, OpNav Instruction 5510.1 (Series). This manual is to be used as a guide by all naval personnel in the handling of classified material. Many of the electronics equipments installed in modern aircraft (and their applicable technical publications) bear security classification; so it is especially important that all personnel in the avionics ratings become thoroughly familiar with security procedures.

It is the personal responsibility of each individual to safeguard all classified material in his possession so as to prevent loss or compromise. It is also his responsibility to avoid unauthorized disclosure of classified information. Material of a classified nature should not be passed on to any person not having the proper security clearance and the need to know.

In contacts with other persons, do not assume that they have the proper security clearance; be SURE before revealing classified information. In conversations and in writing, avoid compromising security. Do not pass any information to unknown personnel until it is sure that the information is not classifed.

Remember that notes jotted down concerning classified material may contain classified information, and must be handled accordingly

CHAPTER 5

ELEMENTARY PHYSICS

The Navy technician is associated with some very complex equipment. He is expected to understand, operate, service, and to an extent maintain these equipments, and to instruct new men so that they can also perform these functions. No matter how complex an item of equipment is, its action can be satisfactorily explained as an application of a few basic principles of physics. In order to understand, operate, and service the equipment and machinery necessary to the operation of the ships and aircraft of the fleet, an understanding of these basic principles is essential. There can be no question that the technician who possesses this understanding is better equipped to meet the demands placed upon him in his everyday tasks.

Physics is devoted to finding and defining problems, as well as to searching for their solutions. It not only teaches a person to be curious about the physical world, but also provides a means of satisfying that curiosity. The distinction between physics and other sciences cannot be well defined, because the principles of physics also pertain to the other sciences. Physics is a basic branch of science and deals with matter, motion, force, and energy. It deals with the phenomena which arise because matter moves, exerts force, and possesses energy. It is the foundation for the laws governing these phenomena, as expressed in the study of mechanics, hydraulics, magnetism, electricity, heat, light, sound, and nuclear physics. It is closely associated with chemistry and depends heavily upon mathematics for many of its theories and explanations.

BASIC CONCEPTS

In any study of physics, it soon becomes obvious that specific words and terms have specific meanings which must be mastered from the very start. Without an understanding of the exact meaning of the term, there can be no real understanding of the principles involved in the use of that term. Once the term is correctly understood, however, many principles may be discussed briefly to illustrate or to emphasize the particular aspects of interest. The first part of this chapter is devoted to definitions of some physical terms and a brief general discussion of certain particular principles of vital interest to all technical personnel.

MEASUREMENT

In all branches of science, measurement is a very important consideration. In order to evaluate results, it is often essential to know how much, how far, how many, how often, or in what direction. As scientific investigations become more complex, measurements must become more accurate, and new methods must be developed to measure new things.

Measurements may be classed in three broad categories—magnitude, direction, and time. These categories are broken down into several types, each with its own standard units. Measurements of direction and time have become fairly well standardized and have comparatively few subdivisions. Magnitude, on the other hand, is an extremely complex category with many classes and subdivisions involved.

To illustrate the complexity of the magnitude category, consider only a few common examples of measurement dealing with magnitude: weight, distance, temperature, voltage, size, loudness, brightness, etc.; then consider measurements based on combinations of magnitude: density (weight per unit volume), pressure (force per unit area), thermal expansion (increase in size per degree change in temperature), etc. In addition, measurements combine categories: The flow of liquids is measured in volume per unit of time, speed is measured in distance per unit of time, rotation is measured in revolutions per minute, frequency is expressed in hertz and so on indefinitely.

The importance of measurement and the necessity of selecting the proper measurement cannot be overemphasized. Several systems of measurement further complicate matters. For example, distance may be measured in feet; or in meters; weight in pounds or in Newtons capacity in quarts or in liters; temperature in degrees Fahrenheit, centigrade, or Kelvin; density in pounds per cubic foot or in grams per cubic centimeter; angles in degrees or in radians; etc.

In this manual, as in many other texts, specific measurements will be described when and as necessary for clarity.

In appendix III of this manual, charts of the U.S. Customary (English) and the International (Metric) System (SI) of measurements are shown. These charts will provide a better understanding of the two systems and will enable conversion between the two easier.

MATTER AND ENERGY

MATTER may be defined basically as "anything that occupies space and has mass." It exists naturally in three states—solid, liquid, or gas. All matter is composed of small particles called molecules. Matter may be changed or combined by various methods—physical, chemical, or nuclear. Matter has many properties; properties possessed by all forms of matter are called general properties, while those properties possessed only by certain classes of matter are referred to as special properties.

ENERGY may be defined basically as "the capacity for doing work." It may be classified in many ways; but for this discussion, energy will be classified as mechanical, chemical, radiant, heat, light, sound, electrical, or magnetic. Energy is constantly being exchanged from one object to another and from one form to another. Physics is primarily the study of matter and energy in their various forms and of the relationships that exist between them.

Law of Conservation

Matter may be converted from one form to another with no change in the total amount of matter. Energy may also be changed in form with no resultant change in the total quantity of energy. In addition, a third statement has been added within the past half century: "Although the total amount of matter and energy remains constant, matter can be converted into energy or energy into matter." This statement is known as the law of conservation for energy and matter. The basic mathematical equation which shows the relationship between matter and energy is as follows:

$$E = mc^2$$

where E represents the amount of energy, m represents the amount of matter (mass), and c represents the velocity of light.

From the equation it may be seen that the destruction of matter creates energy, and that the creation of matter requires expenditure of energy. From this observation it may be implied that a given quantity of matter is the equivalent of some amount of energy. In common usage it is usually stated that matter "possesses" energy.

General Properties of Matter

Matter in all forms possesses certain properties. In the basic definition it has been stated that matter occupies space and has mass. Those two ideas contain most, if not all, of the general properties of matter.

SPACE.—The amount of space occupied by, or enclosed within, the bounding surfaces of a body is called volume. In the study of physics, this concept must be somewhat modified in order to be completely accurate. As stated previously, matter may appear as a solid, as a liquid, or as a gas—each having special properties. In a later section of this chapter it will be shown that for even a specific substance the volume may vary with changes in circumstances. It will also be shown that liquids and solids tend to retain their volume when physically moved from one container to another; gases tend to assume the volume of the container.

It will be discussed at some length later that all matter is composed of atoms and molecules. In order to clarify our concept of "occupying space," we must deal with these minute particles of matter, which are in turn composed of still smaller particles separated from each other by empty space (which contains no matter). This idea is used to explain two general properties of matter—impenetrability and porosity.

Two objects cannot occupy the same space at the same time; this is known as the "impenetrability of matter." The actual space occupied by the individual subatomic particles cannot be occupied by any other matter. The impenetrability of matter may, at first glance, seem invalid when a cup of salt is poured into a cup of water—the result is considerably less than two cups of salt water. However, matter has an additional general property called "porosity" which explains this apparent loss of volume: The water simply occupies space between particles of salt. Porosity is present in all material—but to an extremely wide range of degree. Generally, gases are extremely porous, liquids only slightly so; solids vary over a wide range, from the sponge to the steel ball.

MASS.—The measure of the quantity of matter which a body contains is called its mass. The mass of a body does not change. To explain this, suppose we have a solid rubber ball which has a diameter of 3 inches. The rubber ball contains a definite quantity of matter. It may be compressed and its volume reduced, but the quantity of matter remains the same. The ball may be taken up on a high mountain, or even to the moon, but the quantity of matter in the ball will remain the same.

MOTION may be defined as the "act or process of changing place or position." The "state of motion" refers to the amount and the type of motion possessed by a body at some definite instant (or during some interval) of time. A body at rest is not changing in place or position; it is said to have zero motion, or to be motionless.

The natural tendency of any body at rest is to remain at rest; a moving body tends to continue moving in a straight line with no change in speed or direction. A body which obeys this natural tendency is said to be in uniform motion.

Every object tends to maintain a uniform state of motion. A body at rest never starts to move by itself; a body in motion will maintain its speed and direction unless it is caused to change. In order to cause a body to deviate from its condition of uniform motion, a push or a pull must be exerted on it. This requirement is due to that general property of all matter known as INERTIA.

The greater the tendency of a body to maintain uniform motion, the greater its inertia. To assign a numerical value to the inertia of a body, it is compared with some standard which is assigned the inertia value of 1. The quantitative measure of inertia is called the MASS of the body; therefore since all matter possesses inertia, all matter must also possess mass.

Any change in the state of motion of a body is known as ACCELERATION, and the cause which produces it is called an accelerating force. Acceleration represents the rate of change in the motion of a body, and may represent either an increase or a decrease in speed and/or a change in direction of motion.

FORCE is the action or effect on a body which tends to change the state of motion of the body acted upon. A force may tend to move a body at rest; it may tend to increase or decrease the speed of a moving body; or it may tend to change the direction of motion. The application of a force to a body does not necessarily result in a change in the state of motion; it may only TEND to cause such a change.

A force is any push or pull which acts on a body. Water in a can exerts a force on the sides and bottom of the can. A tug exerts a push or a pull (force) on a barge. A man leaning against a bulkhead exerts a force on the bulkhead.

In the above examples, a physical object is exerting the force and is in direct contact with the body upon which the force is being exerted. Forces of this type are called contact forces. There are other forces which act through empty space without contact—in some cases without even seeming to have any mass associated with them. The force of gravity exerted on a body by the earth—known as the weight of the body—is an example of a force that acts on a body through empty space and without contact. Such a force is known as an action-at-a-distance force. Electric and magnetic forces are other examples of these action-at-a-distance forces. The space through which these action-at-a-distance forces are effective is called a force field.

Force is a VECTOR quantity; that is, it has both direction and magnitude. A force is completely described when its magnitude, direction, and point of application are given. In a force vector diagram, the starting point of the line represents the point of application of the force. (The topic of vectors—properties, functions, uses, and methods of calculation—is discussed in detail in Rate Training Manual, Mathematics Vol. 2, NavPers 10071-B.)

Any given body, at any given time, is subjected to many forces. In many cases, all these forces may be combined into a single RESULTANT force, which may then be used to determine the total effect on the body. Combination of all individual forces into a single resultant involves the use of trigonometry, which is also covered in NavyPers 10071-B.

Each body of matter in the universe attracts every other body with a force which is proportional to the mass of the bodies and inverse to the square of the distance between them. This force is called the UNIVERSAL FORCE OF GRAVITATIONAL ATTRACTION. Since every body exerts this force on every other body, when considering the forces acting on a single body, it is an almost universal practice to resolve all gravitational forces into a single resultant. At or near the surface of the earth, this becomes a fairly simple process—due to its extremely large mass, the earth exerts such a large gravitational attraction that it is entirely practical to ignore all other such attractions and merely use the earth's gravitational attraction as the resultant.

Although gravitational attraction is exerted by each body on the other, in those cases where there is a great difference in the mass of two bodies, it is usually more convenient to consider the force as being exerted by the larger mass on the smaller mass. Thus, it is commonly stated that the earth exerts a gravitational force of attraction on a body. The gravitational attraction exerted by the earth on a body is called GRAVITY.

The gravitational force exerted by the earth on a body is called the WEIGHT of that body, and is expressed in force units. In the English system, force is expressed in pounds. If a body is attracted by a gravitational force of 160 pounds, the body is said to weigh 160 pounds. The gravitational force between two bodies decreases as the distance between them increases; therefore, a body weighs less a mile above the surface of the ocean than it weighs at sea level; it weighs more a mile below sea level.

Conversion of Mass and Weight

The relationship of mass, weight, and gravity may be expressed mathematically by the formula

$$\text{mass} = \frac{\text{weight}}{\text{acceleration due to gravity}}$$

This relationship is valid for any system of measurement, provided only that all measurements are taken in the same system.

In the English system of measurement, the mass is normally measured in slugs, weight in pounds, and acceleration (due to gravity) in feet per second per second. Therefore, the equation in English terms is

$$m = \frac{w(\text{lb})}{g(\text{ft/sec}^2)}$$

(A slug is frequently defined in terms of force and acceleration: A slug is that mass, which, when acted upon by a force of 1 pound, will be accelerated by 32 ft/sec^2.)

In problems involving the use of mass, it is usually convenient to substitute w/32 for m and the weight of the body for w in the equation. (The 32 comes from the fact that the acceleration due to gravity is 32 ft/sec^2.)

Example 1: If a body has a mass of 5 slugs, its weight (in pounds) at sea level (as measured with a spring balance) may be determined from the formula

$$m = \frac{w}{g}$$

Rearranged to solve for the necessary quantity, this formula becomes

$$w = mg$$

Substituting the numerical values,

$$w = 5 \times 32$$

$$w = 160 \text{ lb}$$

The spring-balance weight of the object is 160 lb at sea level.

Example 2: At an altitude where the acceleration due to gravity is only 31.5 ft/sec^2, what is the weight of the 5-slug mass? By using the same equation and substituting numerical values

$$w = mg$$

$$w = 5 \times 31.5$$

$$w = 157.5 \text{ lb}$$

These examples illustrate how weight varies as a result of a change in the force of gravity due to a change in altitude. The value of 32 feet per second per second usually assigned g is only an approximation used when measurements are made at or near sea level. Altitude affects the weight of an object, but its mass remains constant everywhere.

It is interesting to note that spring weighing machines are not legal for trade in most states of the U.S. A spring scale registers the force necessary to overcome the pull which gravitational force exerts on the object being weighed. This gravitational force varies with the altitude of the object on the earth. A balancing scale, usually called a BALANCE, measures mass rather than weight, although the dial is marked in pounds. On a balance, the object to be weighed is compared with a standard unit of mass. The variation due to altitude is canceled because it affects both the standard unit and the object to be weighed. Therefore, the standard mass serves as an accurate unit of measure for all locations on the surface of the earth.

Density and Specific Gravity

The DENSITY of a substance is its weight per unit volume. A cubic foot of water weighs 62.4 pounds; the density of water is 62.4 pounds per cubic foot. (In the metric system the density of water is 1 gram per cubic centimeter.)

The SPECIFIC GRAVITY (S.G.) of a substance is the ratio of the density of the substance to the density of water—

$$\text{S.G.} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Specific gravity is not expressed in units but as a pure number. For example, if a substance has a specific gravity of 4, 1 cubic foot of the substance weighs 4 times as much as a cubic foot of water—62.4 times 4 or 249.6 pounds. In metric units, 1 cubic centimeter of a substance with a specific gravity of 4 weighs 1 times 4 or 4 grams. (Note that in the metric system of units, the specific gravity of a substance has the same numerical value as its density.)

Specific gravity and density are independent of the size of the sample under consideration, and depend only upon the substance of which the sample is made. See table 5-1 for typical values of specific gravity for various substances.

Table 5-1.—Typical values of specific gravity.

Substance	Specific gravity
Aluminum	2.7
Brass	8.6
Copper	8.9
Gold	19.3
Ice	0.92
Iron	7.8
Lead	11.3
Platinum	21.3
Silver	10.5
Steel	7.8
Mercury	13.6
Ethyl alcohol	0.81
Water	1.00

A great deal of ingenuity is often needed to measure the volume of irregularly shaped bodies. Sometimes it is practical to divide a body into a series of regularly shaped parts and then apply the rule that the total volume is equal to the sum of the volumes of all individual parts. Figure 5-1 demonstrates another method of measuring the volume of small irregular bodies. The volume of water displaced by a body submerged in water is equal to the volume of the body.

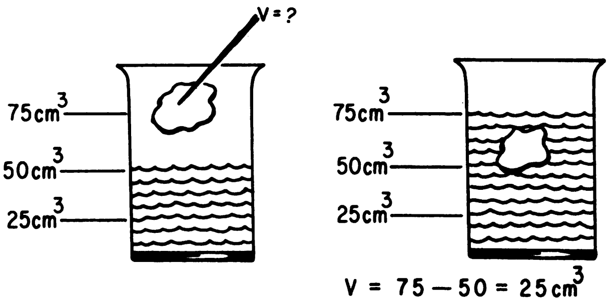


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Figure 5-1.—Measuring the volume of an irregular object.

A somewhat similar consideration is possible for floating bodies. A floating body displaces its own weight of liquid. This may be proved by filling a container to the brim with liquid, then gently lowering the body to the surface of the liquid and catching the liquid that flows over the brim. Weighing the liquid displaced and the original body will prove the truth of the statement.

Pressure and Total Force

Pressure and force, while closely related topics, are not the same thing. A weight of 10 pounds resting on a table exerts a force of 10 pounds. However, the shape of the weight must be taken into consideration to determine the effect of the weight. If the weight consists of a thin sheet of steel resting on a flat surface, the effect is quite different than if the same sheet of steel were resting on a sharp corner.

Pressure is concerned with the distribution of a force with respect to the area over which that force is distributed. Pressure is defined as the force per unit of area, or P = F/A. A flat pan of water with a bottom area of 24 square inches and a total weight of 72 pounds exerts a total force of 72 pounds, or a pressure of 72/24 or 3 pounds per square inch, on the flat table. If the pan is balanced on a block with a surface area of 1 square inch, the pressure is 72/1 or 72 pounds per square inch. An aluminum pan with a thin bottom is suitable for use on a flat surface, but may be damaged if placed on the small block.

This concept explains why a sharp knife cuts more easily than a dull one. The smaller area concentrates the applied force (increases the pressure) and penetrates more easily. For hydraulic applications, the relationship between pressure and force is the basic principle of operation. In enclosed liquids under pressure, the pressure is equal at every point on the surfaces of the enclosing container, and therefore the force on a given surface is dependent on the area. In a system consisting of two cylinders connected by a tube, the force on the pistons is proportional to the area.

Kinetic Energy

Moving bodies possess energy because, by virtue of their mass in motion, they are capable of doing work. The energy of mass in motion is called KINETIC energy, and may be expressed by the equation

$$\text{Kinetic energy} = 1/2\ mv^2$$

where m represents the mass of the body, and v is the velocity of its motion. When the moving body is stopped, it loses its kinetic energy. The energy is not destroyed, but is merely converted into other forms of energy, such as heat and POTENTIAL energy. It is important to remember that bodies at rest also possess energy by virtue of their position.

COMPOSITION OF MATTER

Many basic facts concerning the structure and composition of matter are presented in Basic Electricity and Basic Electronics (in connection with the study of transistors). Study of these basic manuals indicates that all matter is composed of atoms, and that these atoms are, in turn, composed of smaller subatomic particles.

The subatomic particles of major interest in elementary physics are the electron, the proton, and the neutron. They may be considered electrical in nature, with the proton representing a positive charge, the electron representing a negative charge, and the neutron being neutral (neither positive nor negative). Although in general the composition of matter follows a consistent pattern for all atoms, the detailed arrangement of subatomic particles is different for each distinct substance. It is the combination and arrangement of the subatomic particles which imparts the distinguishing chemical and physical characteristics to a substance.

The protons and the neutrons of an atom are closely packed together in a nucleus (core), with the electrons revolving around the nucleus. Atoms are normally considered to be electrically neutral—that is, they normally contain an equal number of electrons and protons; but this condition does not actually prevail under all circumstances. Atoms which contain an equal number of electrons and protons are called balanced atoms; those with an excess or a deficiency of electrons are called "ions."

The proton and the neutron have approximately the same mass, which is approximately 1,836 times the mass of an electron. In any atom, nearly all the mass is contained in the nucleus. It may be assumed that under normal conditions any change in the composition of the atom would involve a change in the number of arrangement of the electrons (due to the smaller mass, they are more easily repositioned). This assumption is generally correct—the most notable exception being in the field of nuclear physics, or nucleonics. In chemistry and in general physics (including electricity and electronics), it is the electron complement that is of major concern.

ELEMENT

The word element is used to denote any one of about 100 substances which comprise the basic substance of all matter. Two or more elements may combine chemically to form a compound; any combination which does not result in a chemical reaction between the different elements is called a mixture. The atom represents the smallest particle of an element. An atom of any one element differs from an atom of any other element in the number of protons in the nucleus; all atoms of a given element contain the same number of protons. Thus, it may be seen that the number of protons in the nucleus determines the type of matter.

The various elements are frequently tabulated according to the number of protons. The number of protons in the nucleus of the atom is referred to as the atomic number of the element.

Nucleus

The study of the nucleus of the atom, known as nucleonics or nuclear physics, is the subject of extensive modern investigation. Experiments on nuclei usually involve the bombardment of the nucleus of an atom, using various types of nuclear particles. By this method the composition of the nucleus is changed, usually resulting in the release of energy. The change to the nucleus may occur as an increase or a decrease in the number of protons and/or neutrons.

If the number of protons is changed, the atom has become an atom of a different element. This process, called "transmutation," is the process sought by the alchemists of the middle ages in their attempts to change various metals into gold. Scientists of that period believed transmutation could be accomplished by chemical means—hence the impetus given to the development of chemistry.

If, on the other hand, only the number of neutrons in the nucleus is changed, the atom remains an atom of the same element. Although all the atoms of any particular element have the same number of protons (atomic number), atoms of certain elements may contain various numbers of neutrons. Hydrogen (the sole exception to the rule that all atoms are composed of three kinds of subatomic particles) normally contains a single proton and a single electron—and no neutrons. However, some hydrogen atoms do contain a neutron. Such atoms (although they are atoms of hydrogen) are known as deuterium, or "heavy hydrogen." (They are called "heavy" because the addition of the neutron has approximately doubled the weight of the atom. Deuterium figured prominently in the research which led to the development of nuclear energy and the atomic bomb.) The atomic weight of an atom is an indication of the total number of protons and neutrons in the atomic nucleus.

Atoms of the same element but which have different atomic weights are called isotopes. Nearly all elements have several isotopes; some are very common, and some are very rare. A few of the isotopes occurring naturally and most of those produced by nuclear bombardment are radioactive or have unstable nuclei. These unstable isotopes undergo a spontaneous nuclear bombardment which eventually results in either a new element or a different isotope of the same element. The rate of spontaneous radioactive decay is measured by "half-life" which is the time required for one-half of a sample of radioactive material to change (by spontaneous radioactive decay) into a different substance.

Electron Shells

The physical and chemical characteristics of an element are determined by the number and distribution of electrons in the atoms of that element. The electrons are arranged in successive groups of electron shells of rotation around the nucleus; each shell can contain no more than a specific number of electrons, as described in Basic Electronics. An INERT element (that is, an element which does not combine chemically with any other element) is a substance in which the outer electron shell of each atom is completely filled. In an element that is not chemically inert, one or more electrons are missing from the outer shell. An atom with only one or two electrons in its outer shell can be made to give up those electrons; an atom whose outer shell needs only one or two electrons to be completely filled can accept electrons from another element which has one or two "extras."

The concept of "needed" or "extra" electrons arises from the basic fact that all atoms have a tendency toward completion (filling) of the outer shell. For atoms that have 3 or more shells, it has been found that if the outermost shell contains 8 electrons it can be considered to be complete and the atom will be stable. An atom whose outer shell has only two electrons would have to collect six additional ones (no easy task, from an energy standpoint) in order to have the eight required for a full shell. A much easier way to achieve the same objective is to give up the two electrons in the outer shell and let the full shell next to it serve as the new outer shell. In chemical terminology, this concept is called valence, and is the prime determining factor in predicting chemical combinations.

COMPOUNDS AND MIXTURES

Under certain conditions, two or more elements can be brought together in such a way that they unite chemically to form a COMPOUND. The resulting substance may differ widely from any of its component elements; for example, ordinary drinking water is formed by the chemical union of two gases—hydrogen and oxygen. When a compound is produced, two or more atoms of the combining elements join chemically to form the MOLECULE that is typical of the new compound. The molecule is the smallest unit that exhibits the distinguishing characteristics of a compound.

The combination of sodium and chlorine to form the chemical compound sodium chloride (common table salt) is a typical example of the formation of molecules. Sodium is a highly caustic poisonous metal containing eleven electrons; its outer shell consists of a single electron, which may be considered "extra" (a valence of +1). Chlorine, a highly poisonous gas with seventeen electrons, "lacks" a single electron (has a valence of -1) to fill its outer shell. When the atom of sodium gives up its extra electron, it becomes a positively charged ion. (It has lost a unit of negative charge.) The chlorine, having taken on this extra unit of negative charge (electron) to fill its outer shell, becomes a negative ion. Since opposite electric charges attract, the ions stick together to form a molecule of the compound sodium chloride.

The attracting force which holds the ions together in the molecular form is known as the "valence bond," a term which is frequently encountered in the study of transistors.

Note that in the chemical combination, there has been no change in the nucleus of either atom; the only change has occurred in the distribution of electrons between the outer shells of the atoms. Also note that the total number of electrons has not changed—there are still the twenty-eight of the original two atoms—although there has been a slight redistribution. Therefore, the molecule is electrically neutral, and has no resultant electrical charge.

Not all chemical combinations of atoms are on a one-for one basis. In the case of drinking water, two atoms of hydrogen (valence of +1) are required to combine with a single atom of oxygen (valence of -2) to form a single molecule of water. Some of the more complex chemical compounds consist of many elements with various numbers of atoms of each. All molecules, like all atoms, are normally considered to be electrically neutral. There are some exceptions to this rule, however, with specific cases of interest being the chemical activity in batteries.

Elements or compounds may be physically combined without necessarily undergoing any chemical change. Grains of finely powdered iron and sulfur stirred and shaken together retain their own identity as iron or sulfur. Salt dissolved in water is not a compound; it is merely salt dissolved in water. Each chemical substance retains its chemical identity, even though it may undergo a physical change. This is the typical characteristic of a MIXTURE.

STATES OF MATTER

In their natural condition, forms of matter are classified and grouped in many different ways. One such classification is in accordance to their natural state—solid, liquid, or gas. This classification is important because of the common characteristics possessed by substances in one group which distinguish them from substances in the other groups. However, the usefulness of the classification is limited by the fact that most substances can be made to assume any of the three forms.

In all matter, the molecules are assumed to be in constant motion, and it is the extent of this motion that determines the state of matter. The moving molecular particles in all matter possess kinetic energy of motion. The total of this kinetic energy is considered to be the equivalent of the quantity of heat in a sample of the substance. When heat is added, the energy level is increased, and molecular agitation (motion) is increased. When heat is removed, the energy level decreases, and molecular motion diminishes.

In solids, the motion of the molecules is greatly restricted by the rigidity of the crystalline structure of the material. In liquids, the molecular motion is somewhat less restricted, and the substance as a whole is permitted to "flow." In gases, molecular motion is almost entirely random—the molecules are free to move in any direction and are almost constantly in collision both among themselves and with the surfaces of the container.

This topic and some of its more important implications are discussed in detail under the heading "Heat" in a later section of this chapter.

Solids

The outstanding characteristic of a solid is the tendency to retain its size and shape. Any change in size or shape requires the exchange of energy. The common properties of a solid are cohesion and adhesion, tensile strength, ductility, malleability, hardness, brittleness, and elasticity. Ductility is a measure of the ease with which the material can be drawn into a wire. Malleability refers to the ability of some materials to assume a new shape when pounded. Hardness and brittleness are self-explanatory terms. The remaining properties are discussed in more detail in the following paragraphs.

COHESION AND ADHESION.—Cohesion is the molecular attraction between like particles throughout a body, or the force that holds any substance or body together. Adhesion is the molecular attraction existing between surfaces of bodies in contact, or the force which causes unlike materials to stick together.

Cohesion and adhesion are possessed by different materials in widely varying degree. In general, solid bodies are highly cohesive but only slightly adhesive. Fluids (liquids and gases), on the other hand, are usually quite highly adhesive but only slightly cohesive. Generally a material having one of these properties to a high degree will possess the other property to a relatively low degree.

TENSILE STRENGTH.— The cohesion between the molecules of a solid explains the property called tensile strength. This is a measure of the resistance of a solid from being pulled apart. Steel possesses this property to a high degree, and is thus very useful in structural work. When a break does occur, the pieces of the solid cannot be stuck back together because merely pressing them together does not bring the molecules into close enough contact to restore the molecular force of cohesion. However, melting the edges of the break (welding) allows the molecules on both sides of the break to flow together, thus bringing them once again into the close contact required for cohesion.

ELASTICITY.—If a substance will spring back to its original form after being deformed, it has the property of elasticity. This property is desirable in materials to be used as springs. Steel and bronze are examples of materials which exhibit this property.

Elasticity of compression is exhibited to some degree by all solids, liquids, and gases; the closeness of the molecules in solids and liquids makes them hard to compress, but gases are easily compressed because the molecules are farther apart.

Liquids

The outstanding characteristic of a liquid is its tendency to retain its own volume while assuming the shape of its container; thus a liquid is considered almost completely flexible and highly fluid.

Liquids are practically incompressible; applied pressure is transmitted through them instantaneously, equally, and undiminished to all points on the enclosing surfaces. Hydraulic apparatus can be used to increase or to decrease input forces, thus providing an action similar to that of mechanical advantage in mechanical systems. Because of these properties, hydraulic servomechanisms have advantages as well as disadvantages and limitations when compared with other systems.

The fluidity of hydraulic liquids permits the component parts of the system to be placed conveniently at widely separated points when necessary. Hydraulic power units can transmit energy around corners and bends without the use of complicated gears and levers. They operate with a minimum of slack and friction, which are often excessive in mechanical linkages. Uniform action is obtained without vibration, and the operation of the system remains largely unaffected by variations in load. The accumulator (which provides the necessary pressurization of the system to furnish practically instantaneous response) can be pressurized during periods of nonaction, thus eliminating the "buildup time" characteristic of electric servos.

However, the hydraulic hoses which transmit the fluid from unit to unit are bulky and heavy compared to electric wiring. Many of the hydraulic fluids in common usage are messy and constitute safety hazards. They contribute to the danger of slipping, they cause deterioration of the insulation on electric wiring, they conduct electricity and thus increase the hazards of short circuiting, and they are flammable.

Rate Training Manual, Fluid Power, NavPers 16193-B, contains considerable detail on the basic theory of hydraulic systems and units.

Gases

The most notable characteristics of a gas are its tendency to assume not only the shape but also the volume of its containers, and the definite relationship that exists between the volume, pressure, and temperature of a confined gas.

The ability of a gas to assume the shape and volume of its container is the result of its extremely active molecular particles, which are free to move in any direction. Cohesion between molecules of a gas is extremely small, so the molecules tend to separate and distribute themselves uniformly throughout the volume of the container. In an unpressurized container of liquid, pressure is exerted on the bottom and the sides of the container up to the level of the liquid. In a gas, however, the pressure is also exerted against the top surface, and the pressure is equal at all points on the enclosing surfaces.

The relationship of volume, pressure, and temperature of a confined gas are explained by Boyle's law, Charles' law, and the general law for gases, as explained later in this chapter.

Many laboratory experiments based on these laws make use of the ideas of "standard pressure" and "standard temperature." These are not natural standards, but are standard values selected for convenience in laboratory usage. Standard values are generally used at the beginning of an experiment, or when a temperature or a pressure is to be held constant. Standard temperature is 0°C, the temperature at which pure ice melts. Standard pressure is the pressure exerted by a column of mercury 760 millimeters high. In many practical uses these standards must be changed to other systems of measurement.

All calculations based on the laws of gases make use of "absolute" temperature and pressure. These topics require a somewhat more detailed explanation.

GAS PRESSURE.—Gas pressure may be indicated in either of two ways—absolute pressure or gage pressure. Since the pressure of an absolute vacuum is zero, any pressure measured with respect to this reference is referred to as "absolute pressure" (psia). In the present discussion, this value represents the actual pressure exerted by the confined gas.

At sea level the average atmospheric pressure is approximately 14.7 pounds per square inch (psi). This pressure would, in a mercurial barometer, support a column of mercury 760 millimeters in height. Thus, normal atmospheric pressure is the standard pressure mentioned previously.

However, the actual pressure at sea level varies considerably; and the pressure at any given altitude may differ from that at sea level. Therefore, it is necessary to take into consideration the actual atmospheric pressure when converting absolute pressure to gage pressure (or vice versa).

When a pressure is expressed as the difference between its absolute value and that of the local atmospheric pressure, the measurement is designated "gage" pressure, and is usually expressed in "pounds per square inch gage" (psig). Gage pressure may be converted to absolute pressure by adding the local atmospheric pressure to the gage pressure.

ABSOLUTE ZERO.—Absolute zero, one of the fundamental constants of physics, is usually expressed in terms of the centigrade scale. Its most predominant use is in the study of the kinetic theory of gases. In accordance with the kinetic theory, if the heat energy of a given gas sample could be progressively reduced, some temperature should be reached at which the motions of the molecules would cease entirely. If accurately determined, this temperature could then be taken as a natural reference, or a true "absolute zero" value.

Experiments with hydrogen (making use of the proven correlation with the volume, temperature, and pressure of gases and by calculations based on this correlation) indicated that if a gas were cooled to -273.16°C (used as -273° for most calculations), all molecular motion would cease and no additional heat could be extracted from the substance. At this point both the volume and the pressure would shrink to zero.

When temperatures are measured with respect to the absolute zero reference, they are said to be expressed in the absolute, or Kelvin, scale. Thus, absolute zero may be expressed either as 0°K or as -273°C.

BOYLE'S LAW.—The English scientist Robert Boyle was among the first to study what he called the "springiness of air." By direct measurement he discovered that when the temperature of an enclosed sample of gas was kept constant and the pressure doubled, the volume was reduced to half the former value; as the applied pressure was decreased, the resulting volume increased. From these observations, he concluded that for a constant temperature the product of the volume and pressure of an enclosed gas remains constant. Boyle's law is normally stated: "The volume of an enclosed dry gas varies inversely with its pressure, provided the temperature remains constant.

In equation form, this relationship may be expressed either

$$V_1P_1 = V_2P_2,$$

or

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where V_1 and P_1 are the original volume and pressure, and V_2 and P_2 are the revised volume and pressure.

CHARLES' LAW.—The French scientist Jacques Charles provided much of the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. Expressed in equation form, this part of the law may be expressed

$$V_1T_2 = V_2T_1,$$

or

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where V_1 and V_2 refer to the original and final volumes, and T_1 and T_2 indicate the corresponding absolute temperatures.

Since any change in the temperature of a gas causes a corresponding change in volume, it is reasonable to expect that if a given sample of a gas were heated while confined within a given volume, the pressure should increase. By actual experiment, it was found that the increase in pressure was approximately 1/273 of the 0°C pressure for each 1°C increase. Because of this fact, it is normal practice to state this relationship in terms of absolute temperature. In equation form, this part of the law becomes

$$P_1T_2 = P_2T_1,$$

or

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

In words, this equation states that with a constant volume, the absolute pressure of a gas varies directly with the absolute temperature.

GENERAL GAS LAW.—The facts concerning gases discussed in the preceding sections are summed up and illustrated in figure 5-2. Boyle's law is expressed in (A) of the figure; while the effects of temperature changes on pressure and volume (Charles' law) are illustrated in (B) and (C), respectively.

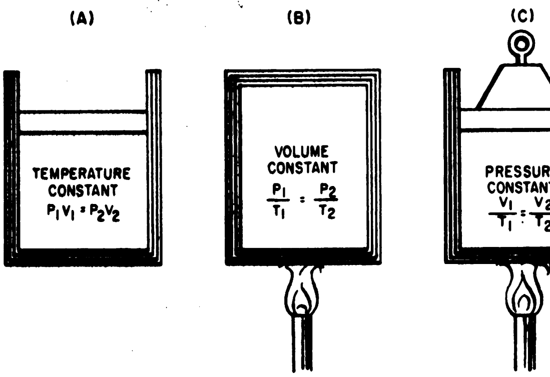

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Figure 5-2.—The general gas law.

By combining Boyle's and Charles' laws, a single expression can be derived which states all the information contained in both. This expression is called the GENERAL GAS EQUATION, a very useful form of which is given by the following equation. (NOTE: The capital P and T signify absolute pressure and temperature, respectively.)

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

It can be seen by examination of figure 5-2 that the three equations are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals T_2 and both can be eliminated from the general formula, which then reduces to the form shown in (A). When the volume remains constant, V_1 equals V_2, thereby reducing the general equation to the form given in (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in (C).

The general gas law applies with exactness only to "ideal" gases in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes.

MECHANICS

Mechanics is that branch of physics which deals primarily with the ideas of force, mass, and motion. Normally considered the fundamental branch of physics, it deals with matter. Many of its principles and ideas may be seen, measured, and tested. Since all other branches of physics are also concerned (to some extent at least) with force, mass, and motion, a thorough understanding of this section will aid in the understanding of later sections of this chapter.

FORCE, MASS, AND MOTION

Each particle in a body is acted upon by gravitational force. However, in every body there is one point at which a single force, equal to the gravitational force and directed upward, would sustain the body in a condition of rest. This point is known as the CENTER OF GRAVITY, and represents the point at which the entire mass of the body appears to be concentrated. The gravitational effect is measured from the center of gravity. In symmetrical objects of uniform mass, this is the geometrical center. In the case of the earth, the center of gravity is near the center of the earth.

When considering the motion of a body, it is usually convenient to describe the path followed by the center of gravity. The natural tendency of a moving body is to move in a manner so that the center of gravity travels in a straight line. Movement of this type is called LINEAR motion.

Some moving bodies, however, do not move in a straight line, but describe an arc or a circular path. Circular motion falls into two general classes—rotation and revolution.

Since objects come in many different shapes and in order to discuss rotary and revolutionary motion, it becomes necessary to consider the location of the center of gravity with respect to the body. (Refer to figure 5-3 for the following discussion.)

In (A), the center of gravity of a ball coincides with the physical center of the ball. However, in the flat washer (B), the center of gravity does not coincide with any part of the object, but is located at the center of the hollow space inside the ring. In irregularly shaped bodies, the center of gravity may be difficult to locate exactly.

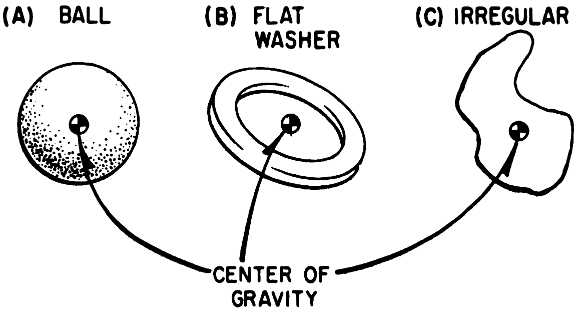

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Figure 5-3.—Center of gravity in various bodies.

If the body is completely free to rotate, the center of rotation coincides with the center of gravity. On the other hand, the body may be restricted in such a manner that rotation is about some point other than the center of gravity. In this event, the center of gravity revolves around the center of rotation. This condition is illustrated in figure 5-4.

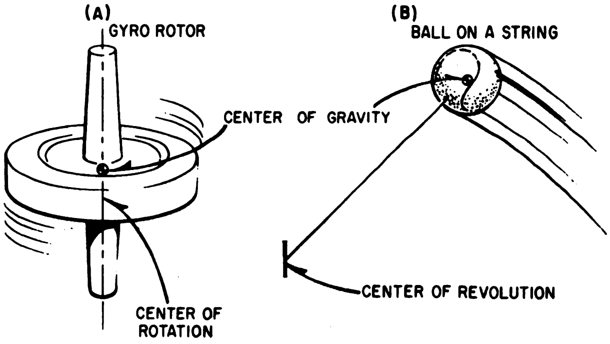

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Figure 5-4.—Center of gravity of rotation.

In general usage, the gyro rotor (A) is said to ROTATE about its axis, and the ball (B) is said to REVOLVE about a point at the center of its path.

MASSES IN MOTION

Any change in the speed or direction of motion of a body is known as acceleration and requires the application of some force. The acceleration of a body is directly proportional to the force causing that acceleration; acceleration depends also upon the mass of the body.

The greater mass of a lead ball makes it harder to move than a wood ball of the same diameter. The wood ball moves farther with the same push.

These observations point to a connection between force, mass, and acceleration, and indicate that the acceleration of a body is directly proportional to the force exerted on that body and inversely proportional to the mass of that body. In mathematical form, this relationship may be expressed as

$$a = \frac{F}{m}$$

or, as it is more commonly stated: Force is equal to the product of the mass and acceleration ($F = ma$).

If the accelerating force is applied to the center of gravity in such a manner as to accelerate the body with no rotation, it is called a TRANSLATIONAL force. A force applied in such a manner as to cause the body to rotate about a point is called a TORQUE force.

Laws of Motion

Among the most important discoveries in theoretical physics are the three fundamental laws of motion attributed to Newton. Although some of these laws have been used in explanations of various topics earlier in this chapter; they are restated and consolidated at this point to clarify and summarize much of the discussion regarding mechanical physics. This restatement and consolidation are also used to introduce additional aspects involving the applications of basic mechanical principles.

1. Every body tends to maintain a state of uniform motion unless a force is applied to change the speed or direction of motion.
2. The acceleration of a body is directly proportional to the magnitude of the applied force and inversely proportional to the mass of the body; acceleration is in the direction of the applied force.
3. For every force applied to a body, the body exerts an equal force in the opposite direction.

Momentum

Every moving body tends to maintain uniform motion. Quantitative measurement of this tendency is proportional to the mass of the body, and also to its velocity. (Momentum = mass x velocity.) This explains why heavy objects in motion at a given speed are harder to stop than lighter objects, and also why it is easier to stop a given body moving at low speed than it is to stop the same body moving at high speed.

WORK, POWER, AND ENERGY

As defined earlier, energy is the capacity for doing work. In mechanical physics, WORK involves the idea of a mass in motion, and is usually regarded as the product of the applied force and the distance through which the mass is moved (work = force x distance). Thus, if a man raises a weight of 100 pounds to a height of 10 feet, he accomplishes 1,000 foot-pounds of work. The amount of work accomplished is the same regardless of the time involved. However, the RATE of doing the work may vary greatly.

The rate of doing work (called POWER) is defined as the work accomplished per unit of time (power = work/time). In the example cited above, if the work is accomplished in 10 seconds, power is being expended at the rate of 100 foot-pounds per second; if it takes 5 minutes (300 seconds), the rate is approximately 3.3 foot-pounds per second.

In the English system of measurements, the unit of mechanical power is called the HORSEPOWER and is the equivalent of 33,000 foot-pounds per minute, or 550 foot-pounds per second. Since energy is readily convertible from one form to another, the work and power measurements based on the conversion of energy must also be readily convertible. As an example, the electrical unit of power is the watt. Electrical energy may be converted into mechanical energy; therefore, electrical power must be convertible into mechanical power. One horsepower is the mechanical equivalent of 746 watts of electrical power, and is capable of doing the same amount of work in the same time.

The accomplishment of work always involves a change in the type of energy, but does not normally change the total quantity of energy. Thus, energy applied to an object may produce work, changing the composition of the energy possessed by the object. When the work stops, energy is no longer being "expended," so energy must once again be converted in form—but not necessarily into its original form.

Efficiency

Provided there is no change in the quantity of matter, energy is convertible with no gain or loss. However, the energy resulting from a given action may not be in the desired form—it may not even be usable in its resultant form. In all branches of physics, this concept is known as EFFICIENCY.

The energy expended is always greater than the energy recovered. An automobile in motion possesses a quantity of kinetic energy dependent on its mass and velocity. In order to stop the car, this energy must be converted into potential energy. When the car is at rest, its potential energy is considerably less than the kinetic energy it possessed while in motion. The difference, or the "energy lost" is converted into heat by the brakes. The heat serves no useful purpose, so the recovered energy is less than the expended energy—the system is less than 100 percent efficient in converting kinetic to potential energy.

The term efficiency is normally used in connection with work and power considerations to denote the ratio of the input to the output work, power, or energy. It is always expressed as a decimal or as a percent less than unity.

Friction

In mechanical physics, the most common cause for the loss of efficiency is FRICTION. Whenever one object is slid or rolled over another, irregularities in the contacting surfaces interlock and cause an opposition to the force being exerted. Even rubbing two smooth pieces of ice together produces friction, although of a much smaller magnitude than in the case of two rough stones. Friction also exists in the contact of air with all exposed parts of an aircraft in flight, as well as in the brakes of the automobile mentioned above.

When a nail is struck with a hammer, the energy of the hammer is transferred to the nail, and the nail is driven into a board. The depth of penetration depends on the momentum of the hammer, the size and shape of the nail, and the hardness of the wood. The larger or duller the nail and the harder the wood, the greater the friction, and therefore the lower the efficiency and less depth of penetration—but the greater the heating of the nail.

Friction is always present in moving machinery, and accounts in part for the fact that the useful work accomplished by the machine is never as great as the energy applied. Work accomplished in overcoming friction is usually not recoverable. Friction can be minimized by decreasing the number of contacting points, by making the contacting areas as small and as smooth as possible, by the use of bearings, or by the use of lubricants.

There are two kinds of friction—sliding and rolling, with rolling friction usually of lower magnitude. Therefore, most machines are constructed so that rolling friction is present rather than sliding friction. The ball bearing and the roller bearing are used to convert sliding friction to rolling friction. A third type, the common (or friction) bearing, utilizes lubricants applied to surfaces which have been made as smooth as possible. Many new types of machines utilize self-lubricating bearings to minimize friction and thus maximize efficiency.

Mechanical Advantage

The concept of mechanical advantage has proved to be one of the great discoveries of science. It permits an increase in force or distance and represents the basic principle involved in levers, block and tackle systems, screws, hydraulic mechanisms, and other work saving devices. However, in the true sense, these devices do not save work, they merely enable humans to accomplish tasks which might otherwise be beyond their capability. For example, a human would normally be considered incapable of lifting the rear end of a truck in order to change a tire; but with a jack, a block and tackle, or a lever, the job can be made comparatively easy.

Mechanical advantage is usually considered with respect to work. Work represents the application of a force through a distance in order to move an object through a distance. Thus, it may be seen that there are two forces involved, each with an appropriate distance. This is illustrated by the simple lever in figure 5-5.

Assuming perfect efficiency, the work input (F_1D_1) is equal to the work output (F_2D_2). Assuming equal distances D_1 and D_2, a force of 10 pounds must be applied at the source in order to counteract a weight of 10 pounds at the load. By moving the fulcrum nearer the load, less force is required to balance the same load. This is a mechanical advantage of force. If the force is applied in such a manner as to raise the load 1 foot, the source must be moved

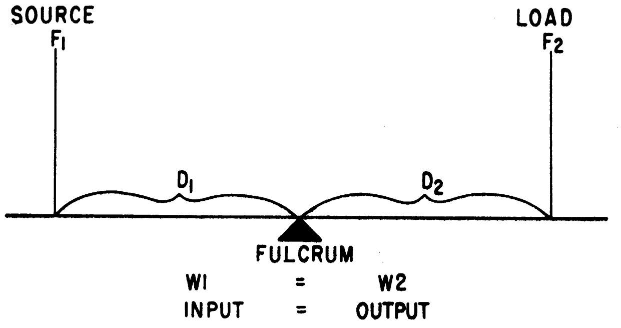

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Figure 5-5.—Mechanical advantage.

through a distance greater than 1 foot. Thus, mechanical advantage of force represents a mechanical disadvantage of distance. By moving the fulcrum nearer the source, these conditions are reversed.

Since the input work equals the output work (assuming no losses), the mechanical advantage may be stated as a ratio of the force or of the distances. In actual situations, friction results in energy loss and decreased efficiency, thereby requiring an even greater input to accomplish the same work.

A more detailed discussion of mechanical advantages and the characteristics of the six basic mechanical devices (the lever, the screw, the inclined plane or wedge, the block and tackle, the wheel and axle, and the gear) is found in the Rate Training Manual, Basic Machines, NavPers 10624-B.

REVOLVING BODIES

Revolving bodies represent masses in motion; therefore, they possess all the characteristics (and obey all the laws) associated with moving bodies. In addition, since they possess a specific type of motion, they have special properties and factors which must be taken into consideration.

Revolving bodies travel in a constantly changing direction, so they must be constantly subjected to an accelerating force. Momentum tends to produce linear motion, but this is prevented by application of a force which restrains the object. This restraining force prevents the object from continuing in a straight line, and is known as CENTRIPETAL force. According to Newton's third law of motion, the centripetal force must be opposed by an equal force which tends to produce linear motion. This second force is known as CENTRIFUGAL force. The two forces, their relationships, and their effects are illustrated in figure 5-6 and the following explanatory example.

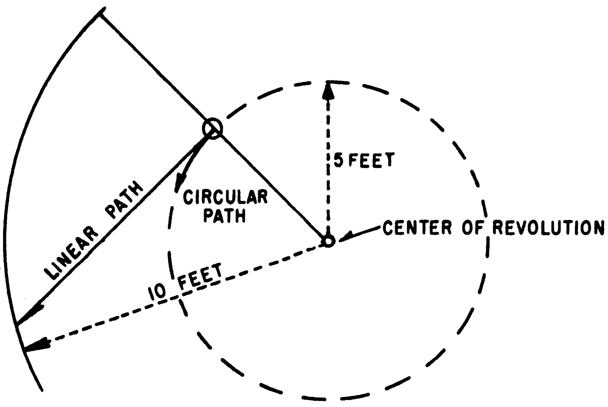

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Figure 5-6.—Forces on revolving bodies.

The various forces involved in revolving bodies may be illustrated by use of a ball and string. A slip knot is tied in the center of a 10-foot length of twine so as to shorten the line to 5 feet; a rubber ball is attached to one end of the string. Holding the other end of the line, whirl the ball slowly in a circle. Note that the ball exerts a force against the hand (through the string); and that in order to restrain the ball in its circular path, the hand must exert a force (through the string) on the ball. As the ball is revolved at higher speed, the forces increase, and the ball continues in a circular path. As the rotational velocity of the ball is gradually increased, note the increasing forces.

At some rotational speed, the forces involved become great enough to overcome inertial friction, and the knot slips. At this time, allow the velocity of the rotation to stabilize (stop increasing in rotational velocity, but not slowing down, either), so that the existing conditions may be analyzed. When the knot slips, the ball is temporarily unrestrained and is free to assume linear motion in the direction of travel at that instant (tangent to the circle at the instantaneous position). The ball travels in a straight line until the string reaches its full length; during this time, no force is exerted on or by the hand. As soon as all the slack is taken up, there is a sharp jerk—an accelerating force is exerted in order to change the direction of motion from its linear path into a circular rotation. The ball again assumes rotational motion, but with an increase in radius.

The ball does not make as many revolutions in the same time (rotational velocity is decreased), but it does maintain its former linear velocity. (The kinetic energy and the momentum of the ball have not changed.) Since the change in direction is less abrupt with a large radius than with a small one, less accelerating force is required, and the hand will feel less force. If the ball is then accelerated to the same rotational velocity as immediately prior to the slipping of the knot, the linear velocity of the ball becomes much greater than before; the centripetal and centrifugal forces are much greater, also.

In this example, it has been assumed that the hand is fixed at a point which represents the center of rotation. This assumption, while somewhat erroneous, does not affect the general conclusions. For practical purposes, the two forces are equal at all points along the string at any given time, and the magnitude of each force is equal at all points along the string.

In summarizing the conclusions reached by the above example and explanation, consider the following relationship:

$$\text{force} = \frac{\text{mass x velocity}^2}{\text{radius}}$$

where velocity represents the linear velocity of the ball. This emphasizes that the centripetal and the centrifugal forces are equal in magnitude and opposite in direction. Each force is directly proportional to the mass of the body and inversely proportional to the radius of rotation. Each force is also proportional to the square of the velocity.

In revolving or rotating bodies, all particles of the matter which are not on the axis of rotation are subjected to the forces just described. The statement is true whether the motion is through a complete circle, or merely around a curve: An aircraft tends to skid when changing course; an automobile tends to take curves on two wheels. The sharper the curve (smaller radius) or the higher the velocity, the greater the tendency to skid.

WAVE MOTION

Wave motion and radiated energy may be compared with the wave motion of water. When a pebble is dropped into a calm pool of water, a series of circular waves travel away from the disturbance. These waves radiate in all directions on the surface of the water until they are absorbed or until they are diverted by coming into contact with an obstruction of some sort. Water waves are a succession of crests and troughs; the distance from the crest of one wave to the crest of the next is called the wavelength. A cork floating on the surface of the water bobs up and down with the waves, but moves very little in the direction of wave travel. Water waves are called transverse waves because the motion of the water particles is up and down, or at right angles (transverse) to the direction in which the wave is traveling.

A second form of wave motion, also involving the motion of particles of matter, may be produced by the physical vibration of a body. An example of this type wave is the sound wave which is produced by striking the tine of a tuning fork. When struck, the tuning fork sets up a vibratory motion. As the tine moves in an outward direction, the air immediately in front of the tine is compressed so that its momentary pressure is raised above that at other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction as a compression wave. When the tine returns and moves in the inward direction, the air in front of the tine is rarefied so that its momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is also propagated, but in the form of a rarefaction (expansion) wave, and follows the compression wave through the medium.

The compression and expansion waves are also called longitudinal waves, because the particles of matter which comprise the medium move back and forth longitudinally in the direction of wave travel. Figure 5-7 is a simplified representation of the use of a tuning fork to produce a longitudinal wave. The transverse wave shown below the longitudinal wave is merely a convenient device to indicate the relative density of the particles in the medium, and does not reflect the movement of the particles.

The progress of any wave requiring movement of particles in the transmission medium

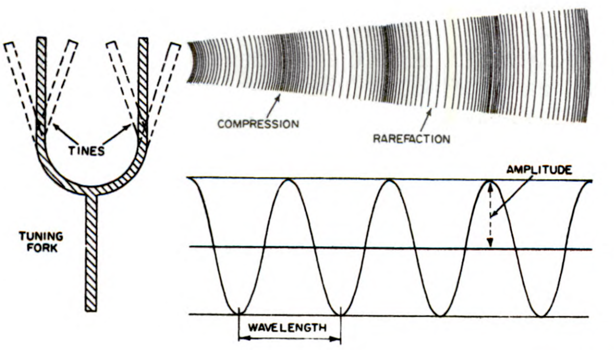

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Figure 5-7.—Compression and expansion wave propagation.

involves two distinct motions: the wave itself moves forward with constant speed, and simultaneously the particles within the medium vibrate. The period of a vibrating particle is the time (t, in seconds) required for the particle to complete one full vibration or cycle. The frequency (f) is the number of vibrations completed per unit of time and is usually expressed in hertz. The period is the reciprocal of the frequency ($t = 1/f$). The amplitude of vibration is the maximum variation of particle density from the equilibrium density.

A body vibrating at a definite rate produces a disturbance that moves away as a wave in the surrounding medium. The velocity of this wave is equal to the wavelength divided by the period. Since the period is the reciprocal of the frequency, the velocity may be expressed as

$$v = f\lambda$$

where v is the velocity of propagation of the wave in the given medium, f is the frequency in hertz, and λ is the wavelength in compatible units of measure. The velocity of propagation may also be described as representing the distance that a wave travels during one period.

Two particles are in phase when they are vibrating with the same frequency, and continually pass through corresponding points of their paths at the same time. For any other condition, the particles are out of phase. Two particles are in phase opposition when they reach their maximum displacements in opposite directions at the same time.

A third type of wave, the electromagnetic wave, does not involve moving particles of matter, but rely on electric and magnetic force fields. The waves previously discussed cannot be propagated in the absence of a conducting medium—electromagnetic waves are propagated most efficiently in the absence of matter. In the electromagnetic wave, two components are required—an electric field and a magnetic field. These two fields are mutually perpendicular to each other and to the direction of propagation. In the particle waves, the velocity of propagation varies with the particular medium, and is comparatively very slow; in the electromagnetic wave, the velocity of propagation is the speed of light (approximately 186,300 miles per second). Examples of electromagnetic waves include heat, light, radio waves, X-rays, cosmic radiations, ultraviolet rays, etc.

All three types of wave motion obey certain common laws and have certain common characteristics: All are periodic; that is, they all constantly repeat the same pattern so that each succeeding wave is the same as the previous one. Each wave displays the same relationships of wavelength, frequency, period, velocity of propagation, amplitude, and phase; and each is subject to the same conditions of reflection and refraction. In the electromagnetic wave, the maxima and minima are correlated with field intensity rather than with particle density or displacement as in the case of the other waves. In the longitudinal wave, the density is related to particle density: in the electromagnetic wave, density is related to the strength of the electric and magnetic fields. In the electromagnetic wave, the electric field and the magnetic field are in phase with each other.

A wavelength is the distance measured along the axis of propagation between two corresponding points of equal intensity which are in phase on adjacent waves. This length can be represented by the distance between maximum points on successive waves.

A line drawn from the source to any point on one of the waves is called a RAY, and indicates the path over which the wave progresses. Although rays do not actually exist, they are frequently used in illustrations as a convenient method of denoting wave propagation. A wavefront is a surface on which all points are in phase. Wavefronts near the source are sharply curved, while those at a distance are almost flat; individual rays from a distant source are considered to be parallel.

REFLECTION

Within a uniform medium, a ray travels in a straight line. Only at the boundary of two media or in an area where the density of the medium changes do the rays change their direction. When an advancing wavefront encounters a medium of different characteristics, some of its energy is reflected back into the initial medium, and some is transmitted into the second medium. When a wavefront encounters a medium which it cannot penetrate, the wave is reflected from the surface.

REFLECTED waves are simply those waves that are neither transmitted nor absorbed, but are thrown back from the surface of the medium they encounter. If a ray is directed against a reflecting surface, the ray striking the surface is called the INCIDENT ray, and the one that bounces back is the REFLECTED ray. An imaginary line perpendicular to the reflecting surface at the point of impact of the incident ray is called the NORMAL. The angle between the incident ray and the normal is called the ANGLE OF INCIDENCE; the angle between the reflected ray and the normal is the ANGLE OF REFLECTION. These terms are illustrated in figure 5-8.

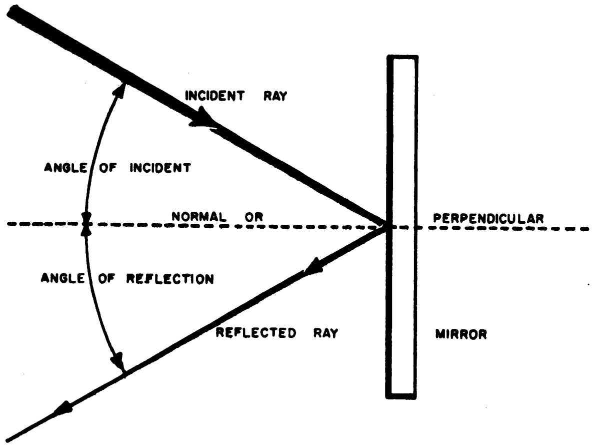

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Figure 5-8.—Terms used to describe the reflection of waves.

If the surface of the medium contacted by the incident ray is smooth and polished (as a mirror), each reflected ray will be thrown back at the same angle as the incident ray. The path of the ray reflected from the surface forms an angle exactly equal to the one formed by its path in reaching the medium. This conforms to the law of reflection which states: The angle of incidence is equal to the angle of reflection.

Diffusion

Reflection from a relatively smooth surface presents few problems. As shown in figure 5-9(A), rays are reflected from a flat smooth surface in an orderly manner with all rays at the same angle and all rays parallel to each order. This is called regular or specular reflection. It is a different matter, however, with a rough surface. The law of reflection is still valid; but due to the rough surface, the angle of incidence is somewhat different for each ray. The reflected rays scatter in all directions, as shown in figure 5-9(B). This form of reflection is called irregular or diffused reflection.

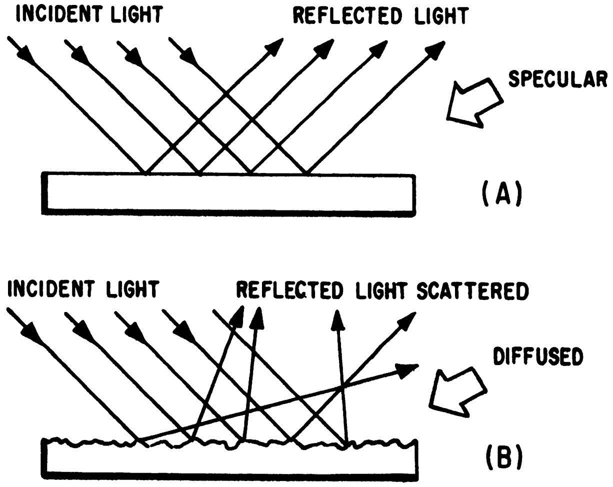

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Figure 5-9.—Reflection from a plane surface. (A) Regular (specular); (B) irregular (diffused).

Focusing

In addition to reflection from a flat surface and diffusion from a rough one, waves may also be focused by reflection from a curved surface. If the reflecting surface is concave, the parallel rays striking its surface are reflected, as shown in figure 5-10(A). The normal is perpendicular to the surface; therefore, the normals on a curved surface are not parallel to one another. The rays come together, or converge, at some point called the focal point. The location of the focal point depends on the rate of curvature of the reflecting surface.

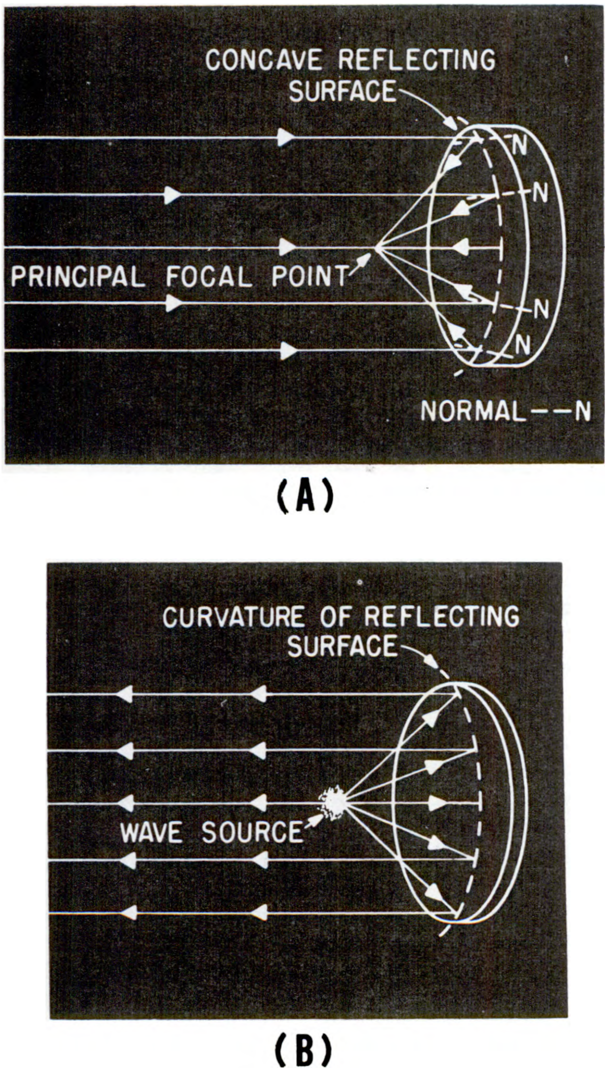

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Figure 5-10.—Reflection from a concave surface. (A) Focusing; (B) illumination.

Illumination

If a point source of waves is located at the focal point of the concave reflector, the reflected rays are formed into a narrow beam, with all reflected rays parallel to one another. This condition is illustrated in figure 5-10(B). In this manner, the intensity is increased (or the area is "illuminated"), because rays that would normally be lost are directed into the beam along with the direct rays.

REFRACTION

The change of direction which occurs when a ray passes from one medium into another of different density is called REFRACTION. It is due to the fact that waves travel at various speeds in different transmission media. Refraction always follows a general rule: When a ray passes from one medium into another of greater density, refraction is toward the normal; when passing into a medium of lesser density, refraction is away from the normal. This is illustrated in figure 5-11.

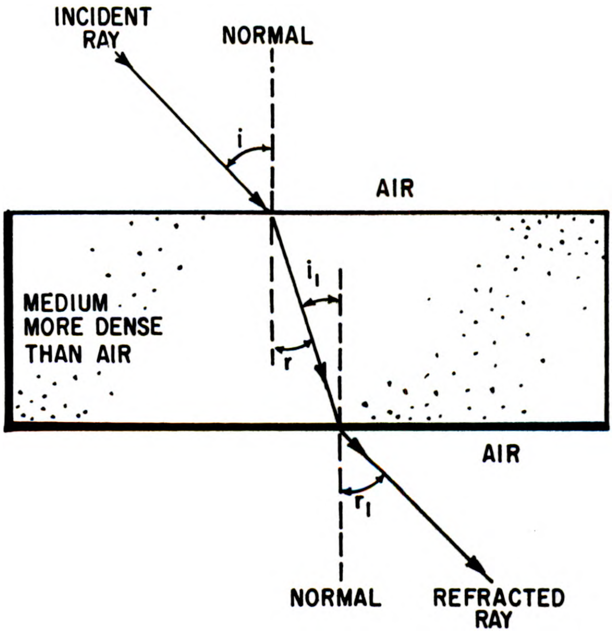

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Figure 5-11.—Refraction of a wave.

DOPPLER EFFECT

When there is relative motion between the source of a wave and a detector of that wave, the apparent frequency at the terminal position differs from the frequency at the source. If the distance between the source and the detector is decreasing, more wavefronts are encountered per second than when the distance is constant. This results in an apparent increase in frequency. Conversely, if the separation is increasing, fewer waves are encountered, with an apparent decrease in frequency.

These apparent changes in frequency are called the Doppler effect, and affect the operation of equipment used to detect and measure wave energy. The amount of change in the apparent frequency depends on the relative velocity of the source and detector and on the velocity of propagation of the wave. The Doppler effect is important in dealing with sound wave propagation as applicable to sonar equipment operation, and in dealing with electromagnetic wave propagation as applicable to radar search, target detection, fire control, navigation, etc. Specific applications of the Doppler effect are not discussed in detail in this chapter but will be discussed in chapter 10 of this manual.

HEAT

Heat represents a form of energy; therefore, it must be readily exchangeable with or convertible into, other forms of energy. The conversion of mechanical energy into heat through friction has been mentioned previously. When a piece of lead is struck a sharp blow with a hammer, part of the kinetic energy of the hammer is converted into heat. In the core of a transformer, electrical and magnetic energy are exchanged; but due to hysteresis and eddy currents, some of the energy is lost as heat. These are some examples of the unwanted conversions, but there are many instances when the production of heat is desirable. Many devices are used almost exclusively to produce heat.

Regardless of how or why it is produced, heat possesses certain characteristics which make it important to the technician. A knowledge of the nature and behavior of heat may prove helpful in understanding the operation of some types of electronics equipment or in determining the cause of nonoperation or faulty operation of others.

NATURE OF HEAT

There are several theories regarding the nature of heat, none of which satisfactorily explain all the characteristics and properties exhibited by heat. The two theories most commonly included in discussions regarding the nature of heat are the kinetic theory and the radiant energy theory.

In the kinetic theory (mentioned earlier in this chapter), it is assumed that the quantity of heat contained by a body is represented by the total kinetic energy possessed by the molecules of the body.

The radiation theory treats radio waves, heat, and light as the same general form of energy, differing primarily in frequency. Heat is considered as a form of electromagnetic energy involving a specific band of frequencies falling between the radio spectrum and light.

A common method used to produce heat energy is the burning process. Burning is a chemical process in which the fuel unites with oxygen, and a flame is usually produced. The amount of heat liberated per unit mass or per unit volume during complete burning is known as the heat of combustion of a substance. By experiment, scientists have found that each fuel produces a given amount of heat per unit quantity burned.

TRANSFER

There are three methods of heat transfer—conduction, convection, and radiation. In addition to these, a phenomenon called absorption is related to the radiation method.

Conduction

The metal handle of a hot pot may burn the hand; a plastic or wooden handle, however, remains relatively cool even though it is in direct contact with the pot. This phenomenon is due to a property of matter known as thermal conductivity. All materials conduct heat—some very readily, some to an almost negligible extent. When heat is applied to a body, the molecules at the point of application become violently agitated, strike the molecules next to them, and cause increased agitation. The process continues until the heat energy is distributed evenly throughout the material. Aluminum and copper are used for cooking pots because they conduct heat very readily to the food being cooked. Wood and plastic are used as handles because they are very poor conductors of heat. As a general rule metals are the best conductors of heat, although some metals are considerably better than others.

Among solids, there is an extreme range of thermal conductivity. In the original example, the metal handle transmits heat from the pot to the hand, with the possibility of burns. The wooden or plastic handle does not conduct heat very well, so the hand is given some protection. Materials that are extremely poor conductors are called "insulators" and are used to prevent heat transfer. Some examples are the wood handle of soldering irons, the finely spun glass or rockwool insulation in houses, or the asbestos tape or ribbon wrapping used on steam pipes.

Liquids are generally poorer conductors than metals. In figure 5-12, note that the ice in the bottom of the test tube has not yet melted, although the water at the top is boiling. Water is such a poor conductor that the rate of heating of the water at the top of the tube is not sufficient to cause rapid melting of the ice at the bottom.

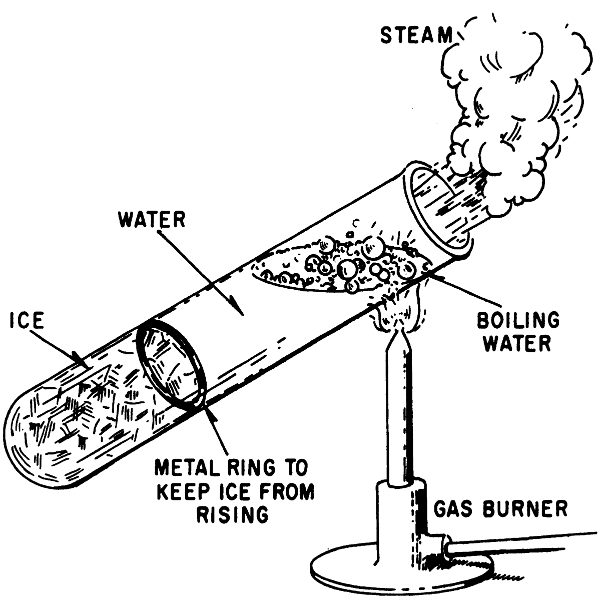

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Figure 5-12.—Water is a poor conductor of heat.

Since thermal conduction is a process by which molecular energy is passed on by actual contact, gases are generally even poorer conductors than liquids because the molecules are farther apart and molecular contact is not so pronounced.

Convection

Convection is the process in which heat is transferred by movement of a hot fluid. For example, an electron tube gets hotter and hotter until the air surrounding it begins to move. The motion of the air is upward because heated air expands in volume and is forced upward by the denser cool air surrounding it. The upward motion of the heated air carries the heat away from the hot tube by convection. Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot vacuum tube can also be increased by providing copper fins to conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown.

A convection process may take place in a liquid as well as in a gas. One example is a transformer in an oil bath. The hot oil is less dense (has less weight per unit volume) and rises, while the cool oil falls, is heated, and rises in turn.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps may be used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations electric fans and blowers are used to aid convection.

Radiation

Conduction and convection cannot wholly account for some of the phenomena that are associated with heat transfer. For example, heating through convection cannot occur in front of an open fire because the air currents are moving toward the fire. It cannot occur through conduction because the conductivity of the air is very low, and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, heat must travel across space by some means other than conduction and convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through molecular contact within some medium, heat from the sun must reach the earth by some other method. (Outer space is an almost perfect vacuum.) Radiation is the name given to this third method by which heat travels from one place to another.

The term radiation refers to the continual emission of energy from the surface of all bodies. This energy is known as radiant energy. It is in the form of electromagnetic waves and is identical in nature with light waves, radio waves, and X-rays, except for a difference in wavelength. Sunlight is a form of radiant heat energy which travels great distances through cold, empty space to reach the earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The net result is that the motion of the molecules in the body is increased, as indicated by an increase in the temperature of the body.

The differences in conduction, convection, and radiation are as follows:

1. Although conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light.

2. Radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass.

3. Although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

Absorption

The sun, a fire, and an electric light bulb all radiate energy, but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies which do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. This is the reason white clothing is worn in the summer. A practical example of the control of heat is the Thermos bottle. The flask itself is made of two walls of "silvered" glass with a vacuum between them. The vacuum prevents the loss of heat by conduction and convection and the "silver" coating prevents the loss of heat by radiation.

The silver-colored bronze paint on the "radiators" in heating systems is used only for decoration and decreases the efficiency of heat transfer. The most effective color for heat transfer is dull black; dull black is the ideal absorber and also the best radiator.

MEASUREMENT OF HEAT

A unit of heat must be defined as the heat necessary to produce some agreed-on standard of change. There are three such units in common use as follows:

1. One British thermal unit (Btu) is the quantity of heat necessary to raise the temperature of 1 pound of water 1°F.

2. One gram-calorie (small calorie) is the quantity of heat necessary to raise 1 gram of water 1°C.

3. One kilogram-calorie (large calorie) is the quantity of heat necessary to raise 1 kilogram of water 1°C. (One kilogram-calorie equals 1,000 gram-calories.) The gram-calorie or small calorie is much more widely used than the kilogram-calorie or large calorie. The large calorie is used in relation to food energy and for measuring comparatively large amounts of heat. Throughout this discussion, unless otherwise stated, the term calorie means gram-calorie. For purposes of conversion, one Btu equals 252 gram-calories or 0.252 kilogram-calories.

The terms quantity of heat and temperature are commonly misused. The distinction between them should be understood clearly. For example, suppose that two identical pans, containing different amounts of water of the same temperature, are placed over identical gas burner flames for the same length of time. At the end of that time, the smaller amount of water will have reached a higher temperature. Equal amounts of heat have been supplied, but the increase in temperatures is not equal. As another example, suppose that the water in both pans is at the same temperature, say 80°F, and both are to be heated to the boiling point. It is obvious that more heat must be supplied to the larger amount of water. The temperature rise is the same for both pans, but the quantities of heat necessary are different.

Mechanical Equivalent

Mechanical energy is usually expressed in ergs, joules, or foot-pounds. Energy in the form of heat is expressed in calories or in Btu's. In a precise experiment in which electric energy is converted into heat in a resistance wire immersed in water, the results show that 4.186 joules equals 1 gram-calorie, or that 778 foot-pounds equals 1 Btu. The following equation is used when converting from the English system to the metric system:

1 Btu = 252 calories

Specific Heat

One important way in which substances differ from one another is that they require different quantities of heat to produce the same temperature change in a given mass of substance. The specific heat capacity of a substance is the quantity of heat needed, per unit mass, to increase the temperature 1°C. The specific heat of a substance is the ratio of its specific heat capacity to the specific heat capacity of water. Specific heat is expressed as a number which, because it is a ratio, has no units and applies to both the English and the metric systems.

Water has a high specific heat capacity. Large bodies of water on the earth keep the air and the surface of the earth at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. Therefore, when the temperature of the air falls below that of such bodies of water, they give off large quantities of heat to the air. This process keeps the atmospheric temperature at the surface of the earth from changing very rapidly.

TEMPERATURE

If an object is hot to the touch, it is said to have a "high" temperature; if it is cold to the touch, it has a "low" temperature. In other words, temperature is used as a measure of the hotness or coldness of an object being described. However, hotness and coldness are only relative. For example, on a cold day, metals seem colder to the touch than nonmetals because they conduct heat away from the body more rapidly. Also, upon leaving a warm room the outside air seems cooler than it really is. Going from the outside cold into a warm room, the room seems warmer than it really is. In other words, the temperature a person feels depends upon the state of his body.

Thermometers

The measurement of temperature is known as THERMOMETRY. Many modern thermometers use liquids in sealed containers. Water was the first liquid used, but because it freezes at 0°C it could not measure temperatures below that point. After much experimentation, scientists decided that the best liquids to use in the construction of thermometers are alcohol and mercury because of the low freezing points of these liquids.

LIQUID THERMOMETERS.—The construction of the common laboratory thermometer gives some idea as to the meaning of a change of 1° in temperature. A bulb is blown at one end of a piece of glass tubing of small bore. The tube and bulb are then filled with the liquid to be used. The temperature of both the liquid and the tube during this process are kept at a point higher than the thermometer will reach in normal usage. The glass tube is then sealed and the thermometer is allowed to cool. During the cooling process, the liquid falls away from the top of the tube and creates a vacuum within the thermometer.

For marking, the thermometer is placed in melting ice. The height of the liquid column is marked as the 0°C point. Next, the thermometer is placed in steam at a pressure of 76 centimeters of mercury and a mark is made at that point to which the liquid inside rises. That is the boiling point or the 100°C mark. The space between these two marks is then divided into 100 equal parts. These spacings are known as DEGREES. It is this type of thermometer that is used almost exclusively in laboratory work and in testing electrical equipment. It is known as the CENTIGRADE thermometer.

NOTE: Centigrade scale or thermometer may be referred to as celsius after the inventor.

In English-speaking countries, the FAHRENHEIT thermometer is commonly used for other than physical or chemical laboratory purposes. The freezing point is marked 32° and the boiling point is marked 212°. The space between these marks is divided into 180 equal parts. These divisions are degrees Fahrenheit, named after the scientist who made the first thermometer of this type. In the U.S., weather reports and room temperatures are given in degrees Fahrenheit.

TEMPERATURE CONVERSION.—There are two systems of temperature measurement; it is frequently necessary to convert from one to the other. The range on the centigrade thermometer from the freezing point to the boiling point is 100°C, and the same range on the Fahrenheit thermometer is 180°F. Thus, over the same temperature range, the liquid moves 180 divisions on the Fahrenheit scale for every 100 divisions on the centigrade scale. A change of 5° on the centigrade scale, therefore, is equal to a change of 9° on the Fahrenheit scale. (The ratio 100/180 reduces to 5/9.) Because zero on the centigrade scale corresponds to 32° on the Fahrenheit scale, a difference in reference points exists between the two scales. (See fig. 5-13.)

To convert from the Fahrenheit scale to the centigrade scale, subtract the 32° difference and multiply the result by 5/9. As an example, convert 68° Fahrenheit to centigrade—

$$\frac{5}{9}(68 - 32)$$

$$\frac{5}{9} \times 36 = 20°\text{C}$$

To convert centigrade to Fahrenheit, the reverse procedure is necessary. First multiply the reading on the centigrade thermometer by 9/5 and then add 32 to the result—

$$\frac{9}{5}(20) + 32$$

$$36 + 32 = 68°\text{F}$$

One way to remember when to use 9/5 and when to use 5/9 is to keep in mind that the Fahrenheit scale has more divisions than the centigrade scale. In going from centigrade to Fahrenheit, multiply by the ratio that is larger; in going from Fahrenheit to centigrade, use the smaller ratio.

Another method of temperature conversion which uses these same ratios is based on the fact that the Fahrenheit and centigrade scales both register the same temperature at -40°; that is, -40°F equals -40°C. This method of conversion, sometimes called the "40-rule," proceeds as follows:

1. Add 40 to the temperature which is to be converted. Do this whether the given temperature is Fahrenheit or centigrade.
2. Multiply by 9/5 when changing centigrade to Fahrenheit; by 5/9 when changing Fahrenheit to centigrade.

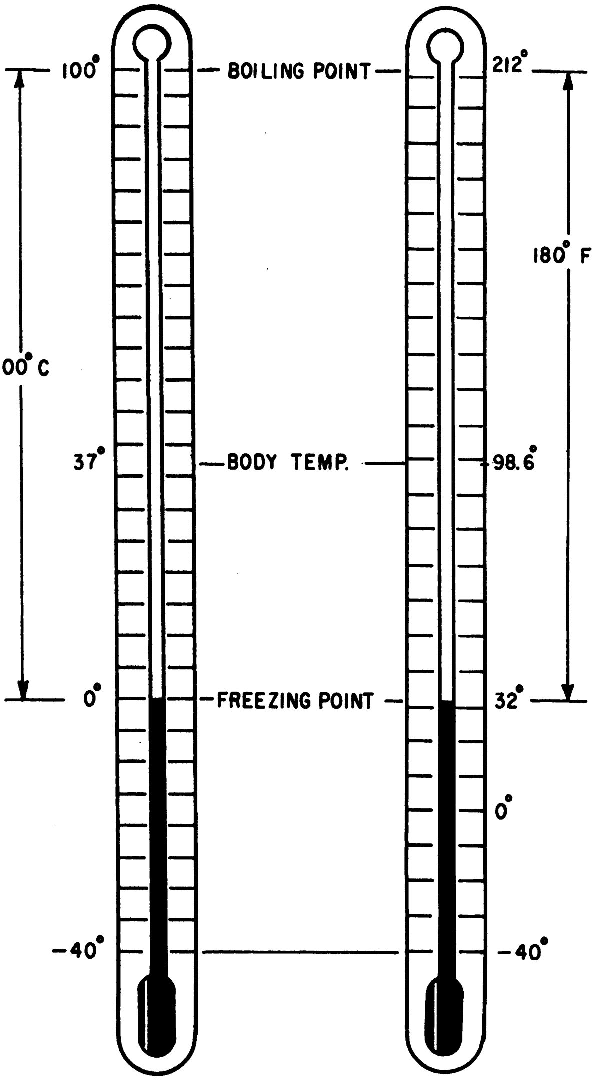

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Figure 5-13.—Fahrenheit and centigrade thermometers.

3. Subtract 40 from the result of step 2. This is the answer.

As an example to show how the 40 rule is used, convert 100°C to the equivalent Fahrenheit temperature:

$$100 + 40 = 140$$

$$140 \times 9/5 = 252$$

$$252 - 40 = 212$$

Therefore, 100°C = 212°F. Remember that the multiplying ratio for converting F to C is 5/9, rather than 9/5. Also remember to always ADD 40 first, then multiply, then SUBTRACT 40, regardless of the direction of the conversion.

It is important that all technicians be able to read thermometers and to convert from one scale to the other. In some types of electronic equipment, thermometers are provided as a check on operating temperatures.

SOLID THERMOMETERS.—Because the range of all liquid thermometers is extremely limited, other methods of thermometry are necessary. Most liquids freeze at temperatures between 0° and -200° centigrade. At the upper end of the temperature range where high heat levels are encountered, the use of liquid thermometers is limited by the high vapor pressures of those liquids. Among the most widely used types of thermometers other than the standard liquid thermometers are the resistance thermometer, and the thermocouple.

The RESISTANCE THERMOMETER makes use of the fact that the resistance of metals changes as the temperature changes. (See chapter 7 of Basic Electricity, NavPers 10086-B.) This type thermometer is usually constructed of platinum wire wound on a mica form and enclosed in a thin-walled silver tube. It is extremely accurate from the lowest temperature to the melting point of the unit.

The THERMOCOUPLE shown in figure 5-14 is essentially an electric circuit. Its operation is based on the principle that when two unlike metals are joined and the junction is at a different temperature than the remainder of the circuit, an electromotive force is produced. This electromotive force can be measured with great accuracy by a galvanometer. Thermocouples can be located wherever measurement of the temperature is important and wires run to a galvanometer located at any convenient point. By means of a rotary selector switch, one galvanometer can read the temperatures at any of a number of widely separated points.

Thermal Expansion

Nearly all substances expand or increase in size when their temperature increases. Railroad tracks are laid with small gaps between the sections to prevent buckling when the temperature increases in summer. Concrete pavement has strips of soft material inserted at intervals to prevent buckling when the sun heats the roadway. A steel building or bridge is put together with red-hot rivets so that when the rivets cool they will shrink and the separate pieces will be pulled together very tightly.

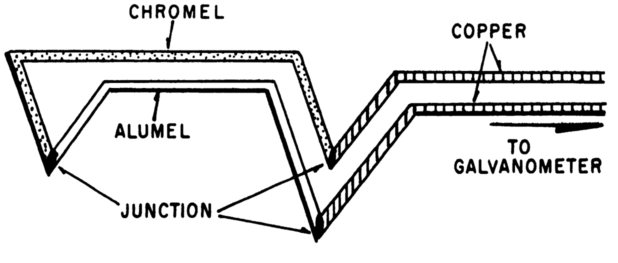

Figure 5-14.—Thermocouple.

As a substance is expanded by heat, the weight per unit volume decreases. This is because the mass of the substance remains the same while the volume is increased by the application of heat. Thus the density decreases with an increase in temperature.

Experiments show that for a given change in temperature, the change in length or volume is different for each substance. For example, a given change in temperature causes a piece of copper to expand nearly twice as much as a piece of glass of the same size and shape. For this reason, the lead wires into an electronic tube cannot be made of copper but must be made of a metal that expands at the same rate as glass. If the metal does not expand at the same rate as the glass, the vacuum in the tube is broken by air leaking past the wires in the glass stem. The metal usually used for this purpose is an alloy called "Covar."

The amount that a unit length of any substance expands for a 1° rise in temperature is known as the coefficient of linear expansion for that substance.

COEFFICIENTS OF EXPANSION.—To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it—its length, the rise in temperature to which it is subjected, and its rate or coefficient of expansion. The amount of expansion is expressed by the following equation:

$$\text{expansion} = \text{coefficient} \times \text{length} \times \text{rise in temperature}$$

or

$$e = kl(t_2 - t_1)$$

In this equation, the letter k represents the coefficient of expansion for the particular substance. In some instances, the Greek letter α (alpha) is used to indicate the coefficient of linear expansion.

PROBLEM: If a steel rod measures exactly 9 feet at 21°C, what is its length at 55°C? (The coefficient of linear expansion for steel is 10×10^{-6}.) If the equation $e = kl\ (t_2 - t_1)$ is used, then

$$e = (10 \times 10^{-6}) \times 9 \times (55 - 21)$$

$$e = 0.000010 \times 9 \times 34$$

$$e = 0.00306$$

This amount, when added to the original length of the rod, makes the rod 9.00306 feet long. (Since the temperature has increased, the rod is longer by the amount of e. If the temperature had been lowered, the rod would have become shorter by a corresponding amount.)

The increase in the length of the rod is relatively small; but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing ships, buildings, and all forms of machinery.

Table 5-2 is a list of the coefficients of linear expansion of some substances.

A practical application for the differences in the coefficients of linear expansion is the thermostat. This instrument comprises two strips of dissimilar metal fastened together. When the temperature changes, a bending takes place due to the unequal expansion of the metals (fig. 5-15). Thermostats are used in overload relays for motors, in temperature-sensitive switches, and in electric ovens. (See fig. 5-16.)

The coefficient of surface or area expansion is approximately twice the coefficient of linear expansion. The coefficient of volume expansion is approximately three times the coefficient of linear expansion. It is interesting to note that in a plate containing a hole, the area of the hole expands at the same rate as the surrounding material. In the case of a volume enclosed by a thin solid wall, the volume expands at the same rate as would a solid body of the material of which the walls are made.

Table 5-2.—Expansion coefficients.

Substance	Coefficient of linear expansion
Aluminum	24×10^{-6}
Brass	20×10^{-6}
Copper	14×10^{-6}
Glass	4 to 9×10^{-6}
Covar	4 to 9×10^{-6}
Steel	10×10^{-6}
Quartz	0.4×10^{-6}
Zinc	26×10^{-6}

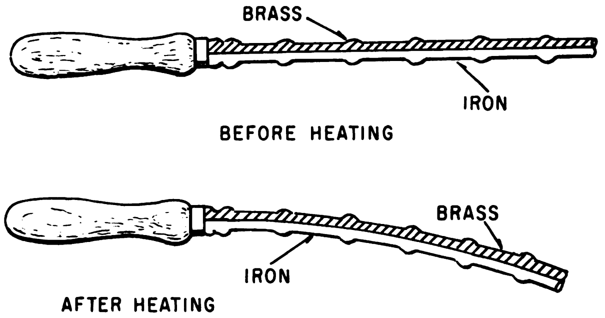

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Figure 5-15.—Compound bar.

CHANGE OF STATE

A thermometer placed in melting snow behaves in a strange manner. The temperature of the snow rises slowly until it reaches 0°C. Provided that the mixture is stirred constantly, it remains at that point until all the snow has changed to water; when all the snow has melted, the temperature again begins to rise. A definite amount of heat is required to change the snow to water at the same temperature. This heat is required to change the water from crystal form to liquid form.

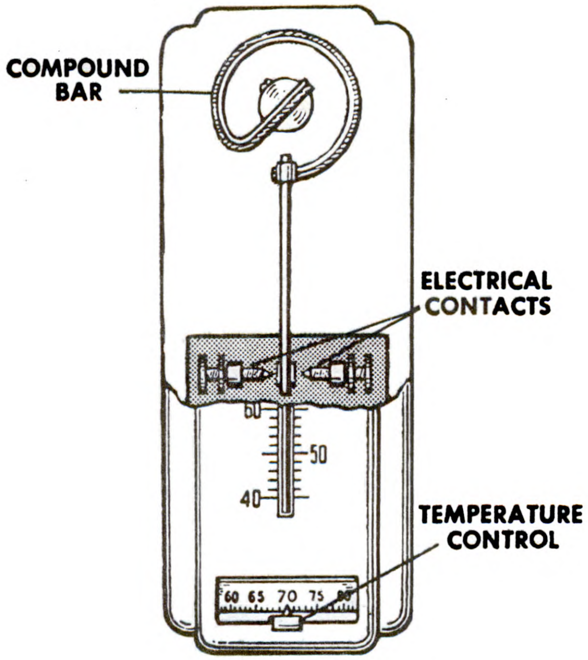

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Figure 5-16.—Thermostat.

Heat of Fusion

Eighty gram-calories of heat are required to change 1 gram of ice at 0°C to water at 0°C. In English units, the heat required to change 1 pound of ice at 32°F to water at 32°F is 144 Btu's. These values are called the HEAT OF FUSION of water. The heat used while the ice is melting represents the work done to produce the change of state. Since 80 calories are required to change a gram of ice to water at 0°C, when a gram of water is frozen it gives up 80 calories.

Many substances behave very much like water. At a given pressure, they have a definite heat of fusion and an exact melting point. There are many materials, however, which do not change from a liquid to a solid state at one temperature. Molasses, for example, gets thicker and thicker as the temperature decreases; but there is no exact temperature at which the change of state occurs. Wax, celluloid, clay, and glass are other substances which do not change from a liquid to a solid state at any particular temperature. In fact, measurements of the glass thickness at the bottom of windows in ancient cathedrals tend to indicate that the glass is still flowing at an extremely slow rate. Most types of solder used in electronics maintenance also tend to become mushy before melting.

Heat of Vaporization

Damp clothing dries rapidly under a hot flatiron but not under a cold one. A pool of water evaporates more rapidly in the sun than in the shade. Thus, it may be concluded that heat has something to do with evaporation. The process of changing a liquid to a vapor is similar to that which occurs when a solid melts.

If a given quantity of water is heated until it evaporates—that is, changes to a gas (vapor)—a much greater amount of heat is used than that which is necessary to raise the same amount of water to the boiling point. For example, several hundred calories are required to change 1 gram of water to vapor at a given temperature. It takes 972 Btu's to change 1 pound of water at 212°F to water vapor (steam) at 212°F. The amount of heat necessary for this change is called the HEAT OF VAPORIZATION of water. Over five times as much heat is required to change a given amount of water to vapor than to raise the same amount of water from the freezing to the boiling point.

BOILING.—When water is heated, some vapor forms before the boiling point is reached. The change from water to vapor occurs as follows: As the water molecules take up more and more energy from the heating source, their kinetic energy increases. The motion resulting from the high kinetic energy of the water molecules causes a pressure which is called the vapor pressure. As the velocity of the molecules increases, the vapor pressure increases. At sea level, atmospheric pressure is normally 29.92 inches of mercury. The boiling point of a liquid is that temperature at which the vapor pressure equals the external or atmospheric pressure. At normal atmospheric pressure at sea level, the boiling point of water is 100°C or 212°F.

While the water is below the boiling point, a number of molecules acquire enough kinetic energy to break away from the liquid state into a vapor. For this reason some evaporation slowly takes place below the boiling point. At the boiling point or above, large numbers of molecules have enough energy to change from liquid to vapor and the evaporation takes place much more rapidly.

If the molecules of water are changing to water vapor in an open space, the air currents carry them away quickly. In a closed container, they rapidly become crowded and some of them bounce back into the liquid as a result of collisions. When as many molecules are returning to the liquid state as are leaving it, the vapor is said to be saturated. Experiments have shown that saturated vapor in a closed container exerts a pressure and has a given density at every temperature.

LIGHT

The exact nature of light is not fully understood, although men have been studying the subject for many centuries. Some experiments seems to show that light is composed of tiny particles, and some indicate that it is made up of waves.

First one theory and then the other attracted the approval and acceptance of the physicists. Today there are scientific phenomena which can be explained only by the wave theory and another large group of occurrences which can be made clear by the particle or corpuscular theory. Physicists, constantly searching for some new discovery which would bring these contradictory theories into agreement, gradually have come to accept a theory concerning light which is a combination of these two views.

According to the view now generally accepted, light is a form of electromagnetic radiation; that is, light and similar forms of radiation are made up of moving electric and magnetic forces.

CHARACTERISTICS

When light waves, which travel in straight lines, encounter any substance, they are transmitted, reflected, or absorbed. (See fig. 5-17.) Those substances which permit clear vision through them, and which transmit almost all the light falling upon them, are said to be transparent. Those substances which allow the passage of part of the light, but appear clouded and impair vision substantially, are called translucent. Those substances which transmit no light are called opaque.

Objects which are not light sources are visible only because they reflect all or part of the light reaching them from some luminous source. If light is neither transmitted nor reflected, it is absorbed or taken up by the medium. When light strikes a substance, some absorption and reflection always take place. No substance completely transmits, reflects, or absorbs all the light which reaches its surface. Figure 5-17 shows how glass transmits, absorbs, and reflects light.

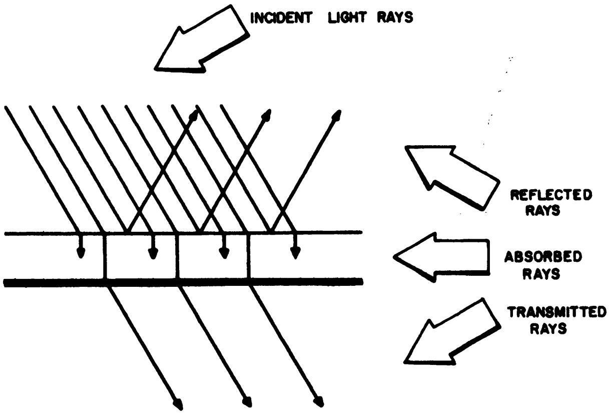

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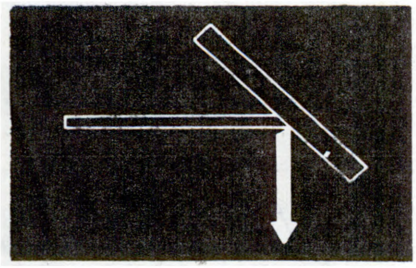
Figure 5-17.—Light rays reflected, absorbed, and transmitted.

Reflection

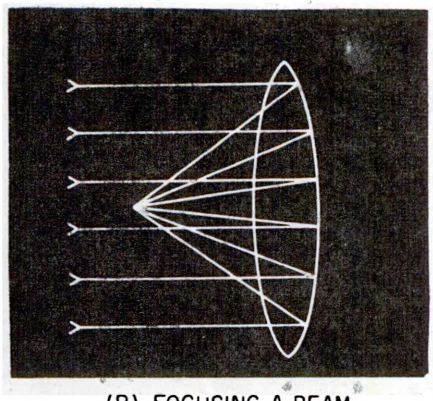
Light waves obey the law of reflection in the same manner as other types of waves. Optical devices incorporated specifically for the purpose of reflecting light are generally classed as mirrors. They may be of a polished opaque surface, or they may be a specially coated glass. In the case of the glass mirror, there is some refraction as well as reflection; however, if the glass is of good quality and not excessively thick, the refraction will cause no trouble. The following discussion is based on the polished surface type mirror.

Several classes of mirrors are illustrated in figure 5-18. All the devices work on the basis of the previously discussed law of reflection, and the applications are only briefly summarized here. Basically, the reflector is used to change the direction of a light beam (A), to focus a beam of light (B), or to intensify the illumination of an area (C).

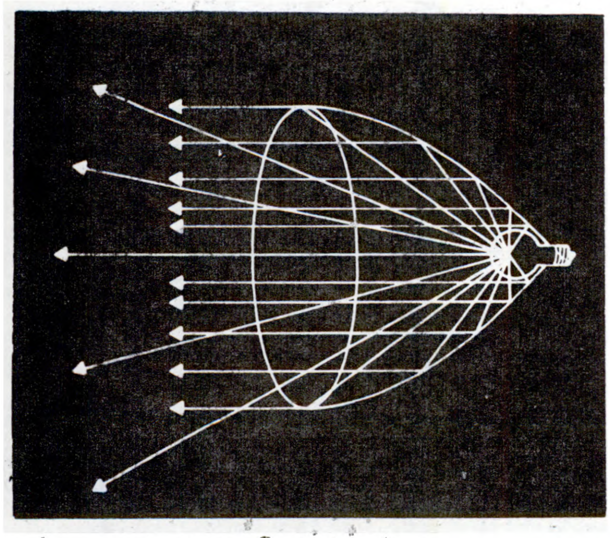
In figure 5-18(A), the angle of the reflected light may be changed to a greater or lesser degree by merely changing the angle at which the incident light impinges upon the mirror. In figure 5-18(B), the focusing action of a concave mirror is indicated. The point of focus may be



(A) CHANGING DIRECTION



(B) FOCUSING A BEAM



(C) ILLUMINATING AN AREA

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Figure 5-18.—Reflectors of light. (A) Changing direction; (B) focusing a beam; (C) illuminating an area.

made any convenient distance from the reflector by proper selection of the arc of curvature of the mirror—the sharper the curvature, the shorter the focal length. In figure 5-18(C), the principal of intensification of illumination for a specific area is illustrated. The flashlight is an example of this application. In the system shown, note that the light source (bulb) is located approximately at the principal focus point, and that all rays reflected from the surface are parallel. Also note that the reflector alone does not concentrate all the rays—some are transmitted without being reflected and are not included in the principal beam.

Refraction

As light passes through a transparent substance, it travels in a straight line. However, as it passes into or out of that substance, it is refracted in the same manner as other waves which were discussed earlier. Refraction of light waves results from the fact that light travels at slightly different velocity in different transparent mediums. In order to simplify the problem of understanding the action of light refraction and to make it possible to predict the outcome of specific applications, many transparent substances have been tested for refractive effectiveness. The ratio of the speed of light in air to its speed in each transparent substance is called the "index of refraction" for that substance. For example, light travels about one and one-half times as fast in air as it does in glass, so the index of refraction of glass is about 1.5. When using the law of refraction in connection with light, a "denser" medium refers to a medium with a higher index of refraction.

Refraction through a piece of plate glass is shown in figure 5-19. The ray of light strikes the glass plate at an oblique angle. If it were to continue in a straight line, it would emerge from the plate at point A; but in accordance with the law of refraction, it is bent toward the normal and emerges from the glass at point B. Upon entering the air, the ray does not continue on its path but is bent away from the normal and along the path BC in the air. If the two surfaces of the glass are parallel, the ray leaving the glass is parallel to the ray entering the glass. The displacement depends upon the thickness of the glass plate, the angle of entry into it, and the index of refraction for the glass.

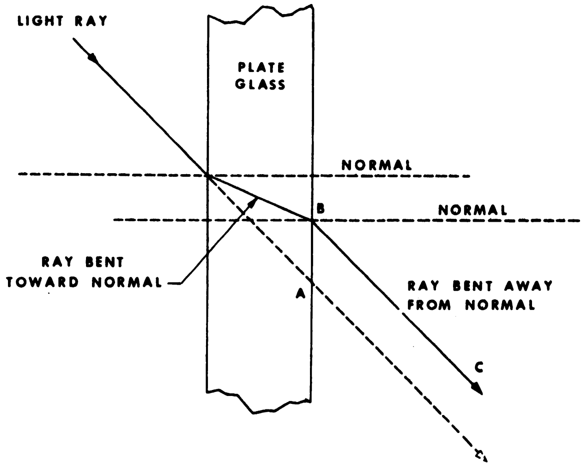

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Figure 5-19.—Refraction through a piece of plate glass.

All rays striking the glass at any angle other than perpendicular are refracted in the same manner. In the case of a perpendicular ray, no refraction takes place, and the ray continues through the glass and into the air in a straight line.

PRISMS.—When a ray of light passes through a flat sheet of glass, it emerges parallel to the incident ray. This holds true only when the two surfaces of the glass are parallel. When the two surfaces are not parallel, as in a prism, the ray is refracted differently at each surface of the glass and does not emerge parallel to the incident ray.

Figure 5-20(A) shows that both refractions are in the same direction, and that the ray coming out of the prism is not parallel to the ray going into it. The law of refraction explains what has happened. When the ray entered the prism, it was bent toward the normal; and when it emerged, it was bent away from the normal. Notice that the deviation is the result of the two normals not being parallel.

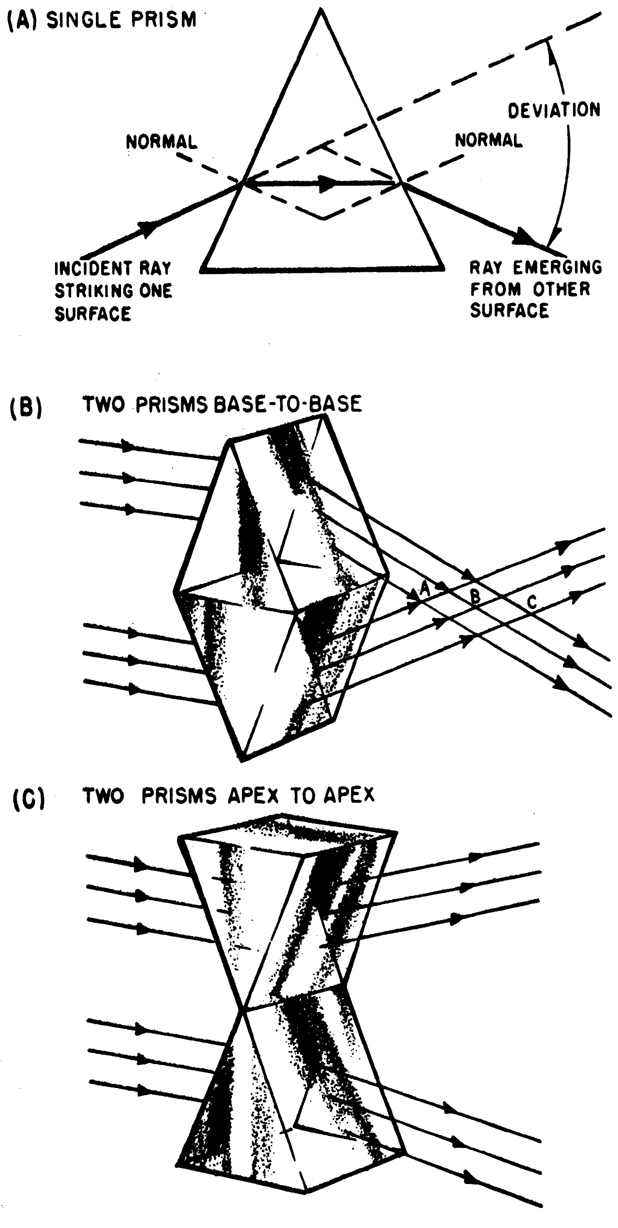
(A) SINGLE PRISM
NORMAL
NORMAL
DEVIATION
INCIDENT RAY STRIKING ONE SURFACE
RAY EMERGING FROM OTHER SURFACE
(B) TWO PRISMS BASE-TO-BASE
A
B
C
(C) TWO PRISMS APEX TO APEX

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Figure 5-20.—Passage of light through a prism. (A) Single prism; (B) two prisms, base to base; (C) two prisms, apex to apex.

If two triangular prisms are placed base to base, as in figure 5-20(B), parallel incident rays passing through them are refracted and caused to intersect. The rays passing through different parts of the prisms, however, do not intersect at the same point. In the case of two prisms there are only four refracting surfaces. The light rays from different points on the same plane are not refracted to a point on the same plane behind the prism. They emerge from the prisms and intersect at different points along an extended common baseline as illustrated by points A, B, and C of figure 5-20(B).

Parallel incident light rays falling upon two prisms that have been joined apex to apex (fig. 5-20(C)), are spread apart. The upper prism refracts light rays toward its base; the lower prism refracts light rays downward toward its base, causing the two sets of rays to diverge.

POSITIVE LENSES.—A positive (convergent) lens acts like two prisms base to base with their surfaces rounded off into a curve. Rays that strike the upper half of the lens bend downward, and rays that strike the lower half bend upward. A good lens causes all wavelengths within each ray to cross at the same point behind the lens as shown in figure 5-21(A).

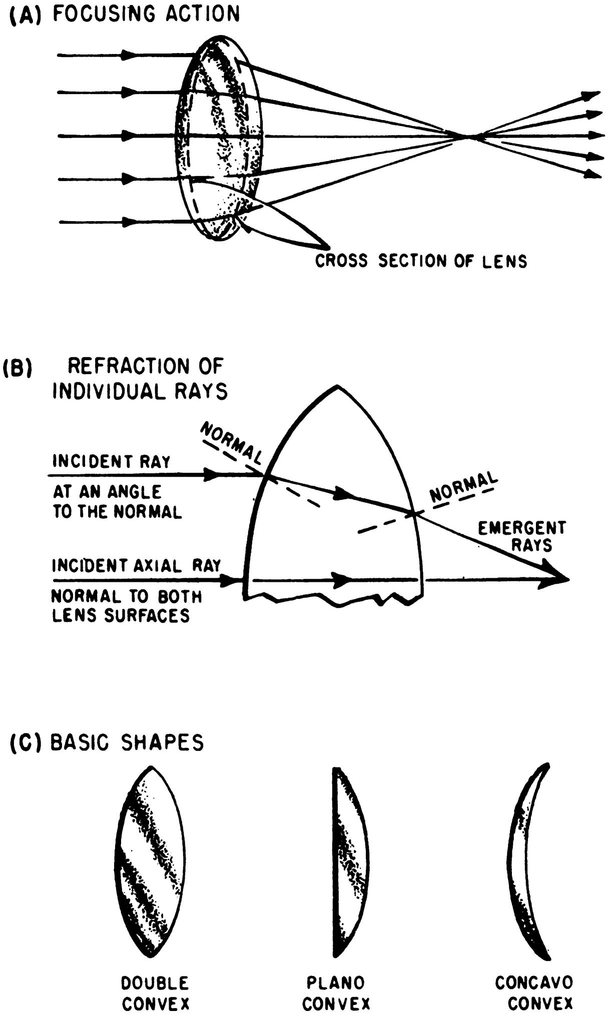

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Figure 5-21.—Positive lenses.

When the incident ray of light enters the denser medium (the lens), it bends toward the normal. When it passes through into the less dense medium (the air), it bends away from the normal. Figure 5-21 (B) illustrates the refraction of only one ray of light, but all rays passing through a positive lens are affected in the same way. All incident light rays either parallel or slightly diverging will converge to a point after passing through a positive lens.

The only ray of light that can pass through a lens without bending is the ray which strikes the first surface of the lens at a right angle, perpendicular or normal to the surface. It passes through that surface without bending and strikes the second surface at the same angle. It leaves the lens without bending. This ray is shown in figure 5-21(B).

Positive lens and convergent lens are synonymous terms, since either of them may be used to describe the action of a lens which focuses (brings to a point of convergence) all light rays passing through it. All simple positive lenses are easy to identify since they are thicker in the center than at the edges. The three most common types of simple positive lenses are shown in figure 5-21(C).

NEGATIVE LENSES.—Figure 5-22 illustrates the refraction of light rays by two prisms apex to apex. If the prism surfaces are rounded, the result is a negative (divergent) lens. A negative lens is called a divergent lens since it does not focus the rays of light passing through it. Light rays passing through a negative lens diverge or spread apart as shown in figure 5-22(A).

Figure 5-22(B) applies the law of refraction to one ray of light passing through a negative lens. Just as in a positive lens, a ray of light passing through the center of a negative lens is not affected by refraction and passes through without bending.

Three simple negative lenses are shown in figure 5-22(C). They are often referred to as concave lenses and are readily identified by their concave surfaces. The simple negative lenses are thicker at the edges than at the center. They are generally used in conjunction with simple positive lenses where their primary use is to assist in the formation of a sharper image by helping to eliminate or subdue various defects present in an uncorrected simple positive lens.

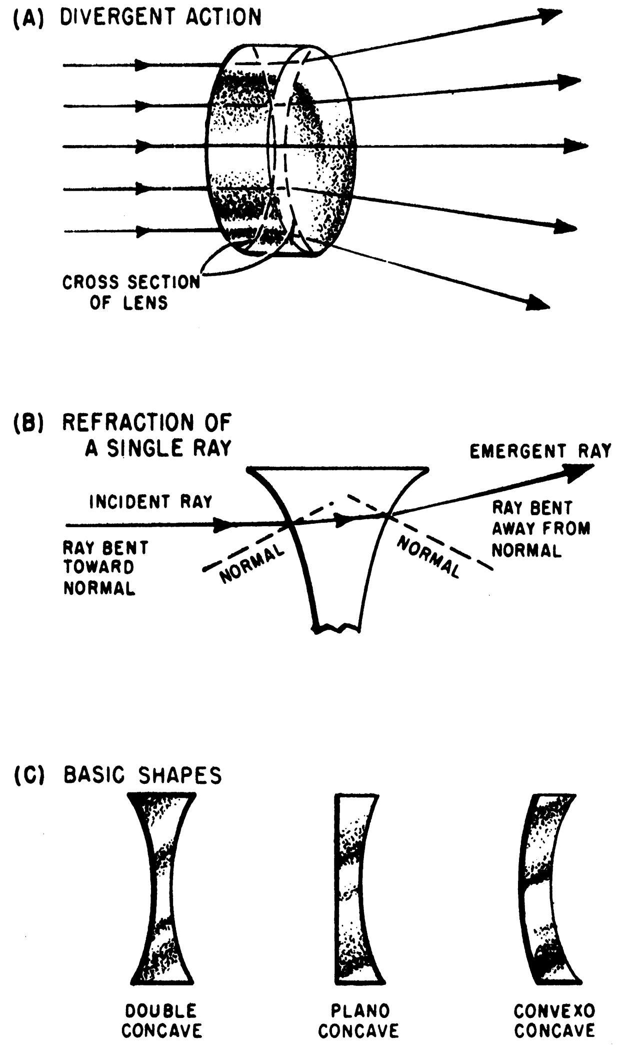

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Figure 5-22.—Negative lenses.

FREQUENCIES AND COLOR

The electromagnetic waves which produce the sensation of light are all very high in frequency, which means that they have very short wavelengths. These wavelengths are measured in millimicrons (millionths of millimeters, or 10^{-9} meters). Figure 5-23 indicates that light with a wavelength of 700 millimicrons is red, and that a light with a wavelength of 500 millimicrons is blue-green. This drawing is subject to erroneous interpretation. In actual fact, the color of light is dependent on its frequency, not its wavelength.

When the wavelength of 700 millimicrons is measured in air, it produces a color known as red, but the same wave measured in another medium has a wavelength other than 700 millimicrons. When red light which has been traveling in air enters glass, it loses speed and its wavelength becomes shorter or compressed, but it continues to be red. This illustrates that the color of light is dependent upon frequency and not on wavelength. The color scale in figure 5-23 is based on the wavelengths in air.

All color-component wavelengths of the visible spectrum are present in equal amounts in white light. Variations in composition of the component wavelengths result in other characteristic colors.

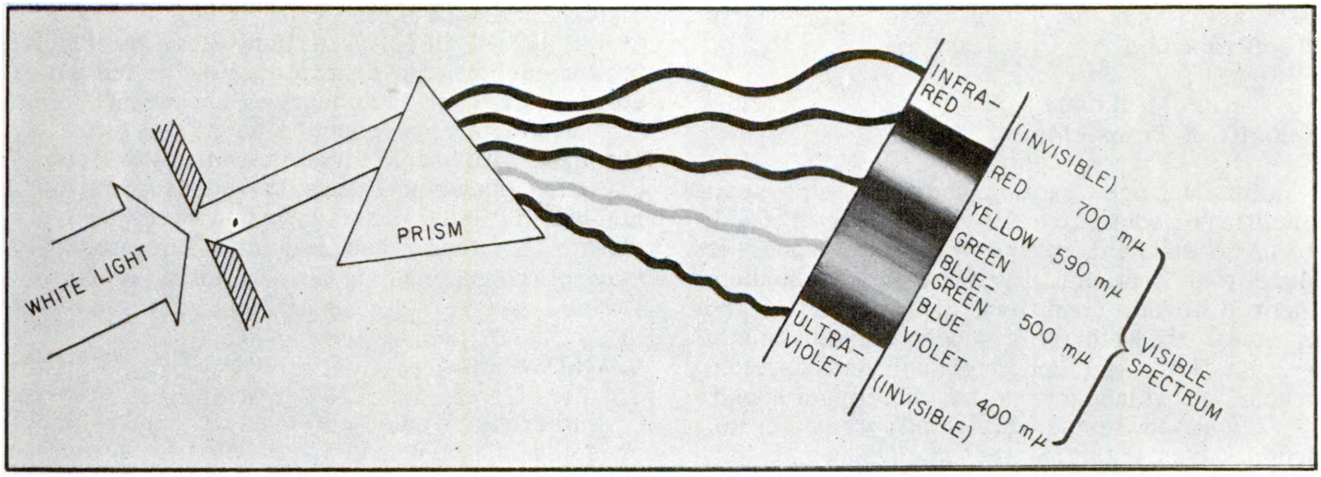
When a beam of white light is passed through a prism, as shown in figure 5-23, it is refracted and dispersed into its component wavelengths. Each of these wavelengths reacts differently on the eye which then sees the various colors that compose the visible spectrum. The visible spectrum is recorded as a mixture of red, orange, yellow, green, blue, indigo, and violet. It can be readily demonstrated that white light results when the PRIMARIES (red, green, and blue) are mixed together in overlapping beams of light. (NOTE: These are not the primaries used in mixing pigments.) Furthermore, the COMPLEMENTARY or secondary colors (magenta, yellow, and cyan) may be shown with equal ease by mixing any two of the primary colors in overlapping beams of light. Thus, red and green light mixed in equal intensities will make yellow light; green and blue will produce blue-green light which is termed cyan; and blue and red light correctly mixed will render magenta (a purplish red).

It should be noted that a few modern texts vary the treatment of the color scale slightly from the seven spectral colors. This is due partly to developments in the mixing values of pigments (paints). This difference in approach is based on a theory that the retina of the eye is equipped with three varying groups of nerves, sensitive roughly to red, green, and blue-violet light.

SOUND

BASIC CONSIDERATIONS

The term sound as generally used refers to hearing; but when used in physics, the term has



REFRACTION OF LIGHT BY A PRISM. THE LONGEST RAYS ARE INFRARED; THE SHORTEST, ULTRAVIOLET.

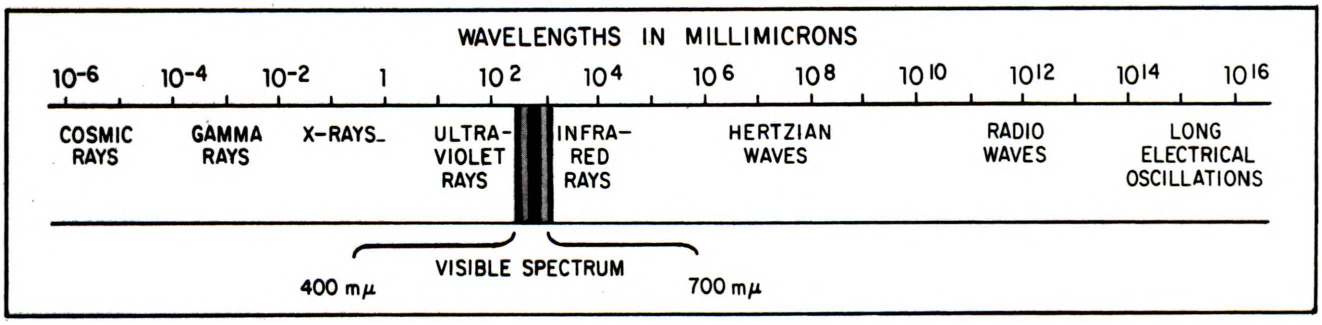


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Figure 5-23.—Electromagnetic wavelengths and the refraction of light.

to do with a particular type of wave motion and with the generation, propagation, transmission, characteristics, and effects of those waves.

One example of the generation and propagation of sound waves is the tuning fork discussed earlier in this chapter. Any object which moves rapidly to and fro, or which vibrates rapidly in such a manner as to disturb the surrounding medium, may become a sound source. Sound requires three components—a source, a medium for transmission, and a detector. As widely different as sound sources may be, the waves they produce have certain basic characteristics.

Wave Motion

Sound waves are longitudinal type waves which rely on a physical medium for propagation and transmission. Since the waves are transmitted by the compression and rarefaction of particles of matter in the medium, they cannot be transmitted through a vacuum. Sound waves are similar to waves of other types in that they can be reflected, absorbed, or refracted according to the laws previously discussed; they are also subject to the Doppler effect. Doppler effect will be discussed in detail later in this manual.

The major differences between the waves of sound and the waves of heat and light are the frequencies, the nature of the wave, and the velocities of wave travel.

Frequencies

Sound waves vary in length; a long wavelength is heard as a low sound, while a short wavelength is heard as a high sound. If the sound is below 15 hertz or above 20,000, it normally cannot be heard by the human ear. The frequency range over which sound can be heard is called the audible range, and the sounds heard are known as sonics. Sounds below 15 hertz are subsonics; those above 20,000 hertz are ultrasonics.

Conduction Media and Velocity of Transmission

In any uniform medium under given physical conditions, sound travels at a definite speed. In some substances, the velocity of sound is higher than in others. Even in the same medium under different conditions of temperature and pressure, the velocity of sound varies. Density and elasticity of a medium are basic physical properties which govern the velocity of sound.

At a given temperature and pressure, all sound waves travel at the same speed in air, regardless of frequency or wavelength. The speed of sound, however, does increase with temperature at the rate of 2.0 feet per second (fps) per degree centigrade. For practical purposes, the speed of sound in air may be considered 1,100 fps. Refer to table A-5-3 for speed of sound in various media at different temperatures.

Table 5-3.—Comparison of velocity of sound in various media.

Medium	Temperature (°F)	Velocity (ft/sec)
Air	32	1,087
Air	68	1,127
Fresh water	32	4,629
Fresh water	68	4,805
Salt water	32	4,800
Salt water	68	4,953
Steel	32	16,410
Steel	68	16,850

As previously stated, a sound wave is a compressional wave transmitted through an elastic medium. Sound travels faster through water (4,800 fps) than air (1,087 fps) because the elasticity of water is greater than that of air.

For a fixed temperature, the velocity of sound is constant for any medium and is independent of the period, frequency, or amplitude of the disturbance. Thus, the velocity of sound in air at 0°C (32°F) is 1,087 fps and increases by 2 fps for each degree centigrade rise in temperature (1.1 fps for each degree Fahrenheit).

The velocity of sound also varies with a change in altitude. With an increase in altitude, the atmospheric pressure is reduced, and the medium is less dense. Sound waves travel slower in a less dense medium. Therefore, it may be considered that the velocity of sound varies inversely with the altitude.

Characteristics

Numerous terms are used to convey impressions of sounds, including whistle, scream, rumble, and hum. Most of these are classified as noises in contrast to musical tones. The distinction is based on the regularity of the vibrations, the degree of damping, and the ability of the ear to recognize components having a musical sequence.

The ear can distinguish tones that are different in pitch, intensity, or quality. Each of these characteristics is associated with one of the properties of the vibrating source or of the waves that the source produces. Thus, pitch is determined by the number of vibrations per second, intensity by the amplitude of the wave motion, and quality by the number of overtones (harmonics) which the wave contains. A sound wave can best be described by its frequency rather than by its velocity or wavelength, as both the velocity and the wavelength change when the temperature of the air changes.

PITCH.—The term pitch is used to describe the frequency of a sound. The outstanding recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a tone is proportional to the number of compressions and rarefactions received per second, which in turn is determined by the vibration frequency of the sounding source.

Pitch is usually measured by comparison with a standard. The standard tone may be produced by a tuning fork of known frequency or by a siren whose frequency is computed for a particular speed of rotation. By regulating the speed, the pitch of the siren is made equal to that of the tone being measured. The ear can determine this equality directly if the two sources are sounded alternately, or by the elimination of beats by regulating the speed of the siren if the two sources are sounded together.

INTENSITY.—When a bell rings, the sound waves spread out in all directions and the sound is heard in all directions. When a bell is struck lightly, the vibrations are of small amplitude and the sound is weak. A stronger blow produces vibrations of greater amplitude in the bell, and the sound is louder. It is evident that the amplitude of the air vibrations is greater when the amplitude of the vibrations of the source is increased. Hence, the loudness of the sound depends on the amplitude of the vibrations of the sound waves. As the distance from the source increases, the energy in each wave spreads out, and the sound becomes weaker.

The intensity of sound is the energy per unit area per second. In a sound wave of simple harmonic motion, the energy is half kinetic and half potential; half is due to the speed of the particles, and half is due to the compression and rarefaction of the medium. These two energies are 90° out of phase at any instant—that is, when the speed of particle motion is at a maximum, the pressure is normal; and when the pressure is at a maximum or a minimum, the speed of the particles is zero.

The loudness of sound depends upon both intensity and frequency. The intensity of a sound wave in a given medium is proportional to the following 4 quantities:

1. Square of the frequency of vibration.
2. Square of the amplitude.
3. Density of the medium.
4. Velocity of propagation.

At any distance from a point source of sound, the intensity of the wave varies inversely as the square of the distance from the source.

As a sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave will be. It can be shown that the intensity is proportional to the square of the pressure variation regardless of the frequency. Thus, by measuring pressure changes, the intensities of sounds having different frequencies can be compared directly.

QUALITY.—Most sounds and musical notes are not pure tones. They are mixtures of tones of different frequencies. The tones produced by most sources can be represented by composite waves in which the sound of lowest pitch, the fundamental tone, is accompanied by several harmonics or overtones having frequencies that are 2, 3, 4 or more times that of the fundamental frequency. The quality of a tone depends on the number of overtones present and on their frequencies and intensities relative to the fundamental tone. It is this characteristic of difference in quality that distinguishes tones of like pitch and intensity when sounded on different types of musical instruments (piano, organ, violin, etc.).

ACOUSTICS

Acoustics is the science of sound, including its propagation, transmission, and effect. The performance of an announcing system or sound system when used in a room or enclosed space depends on the acoustical characteristics of the enclosure. Sound originating in an enclosed space is partly reflected and partly absorbed by enclosing surfaces such as the walls, ceiling, and floor of a room. This action introduces echoes and reverberations, which may seriously impair the quality or character of the sound.

Acoustical Disturbances

Light is often thought of first whenever reflection is discussed; however, reflection is equally common in other waves. As an example, echoes are caused by reflection of sound waves.

ECHO.—An ECHO is the repetition of a sound caused by the reflections of sound waves. When a surface of a room is situated so that a reflection from it is outstanding, it appears as a distinct echo, and is heard an appreciable interval later than the direct sound. If the surface is concave, it may have a focusing effect and concentrate the reflected sound energy at one locality. Such a reflection may be several levels higher in intensity than the direct sound, and its arrival at a later time may be particularly disturbing. Some possible remedies for this condition are as follows:

1. Cover the offending surface with absorbing material to reduce the intensity of the reflected sound.
2. Change the contour of the offending surface and thus send the reflected sound in another direction.
3. Locate the loudspeaker in a different position.
4. Vary the amplitude or the pitch of the signal.

REVERBERATION is the persistence of sound due to the multiple reflection of sound waves between several surfaces of an enclosure. It is one of the most common acoustical defects of a large enclosure. Its duration varies directly with the time interval between reflections (the size of the enclosure) and inversely with the absorbing efficiency of the reflecting surfaces. The result is an overlapping of the original sound and its images. If excessive, reverberation causes a general confusion that is detrimental to speech intelligibility. The hangar deck of an aircraft carrier is an example of an extremely reverberant area. The volume is large, and the hard steel interior surfaces offer very little absorption to sound.

If a single loudspeaker is mounted in a large reverberant area, such as a hangar deck, the intelligibility directly in front of the loudspeaker is satisfactory. The intelligibility decreases rapidly with an increase of either the distance from the loudspeaker or the angle between the listener and the loudspeaker's sound axis. In other words, sound from a loudspeaker in a reverberant space is composed of direct sound that reaches the listener directly without any reflection, and indirect sound that has received at least one reflection.

Intelligibility under these conditions is related to the ratio of direct sound to indirect sound. As the listener moves away from the loudspeaker, the ratio of direct sound to indirect sound at the listening position decreases, and the intelligibility decreases correspondingly. Hence, in a highly reverberant space the intelligibility decreases with distance from the loudspeaker.

To prevent the sound from becoming unintelligible in a highly reverberant space, several speakers can be installed about the area rather than just one. The power requirements remain the same; one 25-watt speaker could be replaced by 5 speakers, each consuming 5 watts. This would greatly increase the direct-to-indirect sound ratio.

INTERFERENCE.—Two sound waves moving through the same medium at the same time will advance independently, each producing the same disturbance as if it were alone. The resultant of the two waves can be obtained by adding algebraically the ordinates (instantaneous magnitudes) of the component waves.

Two sound waves of the same frequency, in phase with each other and moving in the same direction are additive. The resultant wave is in phase with, and has an amplitude equal to, the sum of the component waves.

Two sound waves of the same frequency, in phase opposition and moving in the same direction, are subtractive. If the component waves have equal amplitudes, the resultant wave is zero. This addition or subtraction of waves is often called interference.

Two sound waves of slightly different frequency and moving in the same direction produce a beat note. If the two waves originate from two vibrating sources at the same point, and the frequency of one wave is one vibration per second greater than that of the other at a particular instant, the sources will produce additive disturbances at some points and subtractive disturbances at some other points on the relative positions of the waves. These changes will continue to occur as long as the sources are kept vibrating.

The resultant wave has a periodic variation in intensity at a frequency equal to the difference between the original frequencies of the component waves. The difference frequency, referred to as the beat frequency, produces a type of pulsating interference particularly noticeable in sound waves. The effect of beat frequency, called beats, produces alternately loud and soft pulses or throbs. The effect is most pronounced when the component waves have equal amplitudes.

STANDING WAVES.—Two sound waves of equal frequency and amplitude moving in opposite directions through the same medium may produce standing waves. Standing waves are set up by the reaction of the two waves on each other. At certain points they are in phase and at other points they are 180° out of phase. Because their amplitudes are equal, when the two waves act in opposition on a particle, the particle remains motionless. At these points in a standing wave, there is no vibration and the points are called nodes. At the points where the two waves reinforce each other they produce maximum vibrations on a particle. These points are called antinodes. The distance between successive nodes (or antinodes) is a half wavelength.

RESONANCE.—Resonance, or sympathetic vibration, is a common problem encountered in acoustics. It is somewhat more serious than some of the other problems discussed, because the possibility exists for damage to equipment. Reverberation and resonance are frequently confused, but they are distinctly different in nature. Reverberation is a result of the reflection of sound waves and of the interaction between the direct and reflected sound. There is only a single source involved. In resonance, however, the offending object becomes a sound source under certain conditions. This may be explained by the following example:

Assume that the natural frequency of vibration of a steel shaft, which is weighted on one end and held firmly on the other, is 25 vibrations per second. Suppose that with the system at rest, a sound wave produces a force which acts on the shaft with a to-and-fro motion 125 times per second. This force sets the system vibrating at 125 vibrations per second. These vibrations would be of a small amplitude because the rod and weight are trying to vibrate at their natural rate of only 25 vibrations per second. During part of the time the system is resisting the driving force. The motion of the system in this case is called a forced vibration.

If the force is slowed from 125 vibrations per second to its natural frequency of 25 vibrations per second, the amplitude of vibration becomes very large. The amplitude will build up to a point where the driving force is enough to overcome the inertia of the system. When these conditions exist, the system is said to be in resonance with the driving force, and sound waves are produced by this vibration.

A common example of resonance is found in a crystal oscillator circuit. When an alternating voltage is applied to a crystal that has the same mechanical (resonant) frequency as the applied voltage, it vibrates and only a small applied voltage is needed to sustain vibration. In turn, the crystal generates a relatively large voltage at its resonant frequency.

Measurement of Sound

The range of sound that the human ear can detect varies with the individual. The normal range extends from about 20 to 20,000 vibrations per second. In the faintest audible speech sounds, the intensity at the ear is about 10^{-16} watts/cm^2. At the threshold of feeling, the maximum intensity that the ear records as sound is about 10^{-4} watts/cm^2.

The human ear is a nonlinear unit that functions on a logarithmic basis.

If the ear is tested with tones of any one frequency, the threshold of audibility is reached when the intensity is reduced to a sufficiently low level so that the auditory sensation ceases. On the other hand, the threshold of feeling is reached when the intensity is increased to a sufficiently high level so that the sound produces the sensation of feeling and becomes painful. If this procedure is performed over a wide frequency range, the data can be used to plot two curves, one for the lower limit of audibility and the other for the maximum auditory response (fig. 5-24). Below the lower curve, the sound is too faint to be audible. Above the upper curve, the sensation is one of feeling rather than of hearing; that is, the sensation of sound is masked by that of pain. The area between the two curves shows the pressure ranges for auditory response at various frequencies. Note that the scales of frequency and pressure are logarithmic. An advance of one horizontal space doubles the frequency, and an advance of one vertical space multiplies the pressure by ten.

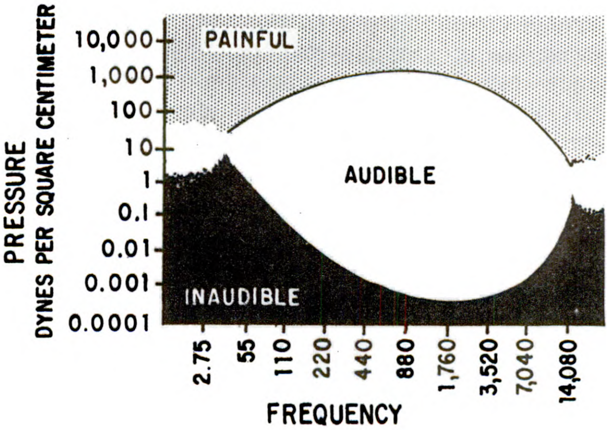

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Figure 5-24.—Field of audibility.

SOUND UNITS.—The loudness of sound is not measured by the same type of scale used to measure length. Units of sound measurement are used that vary logarithmically with the amplitude of the sound variations. These units are the bel and decibel, which refer to the difference between sounds of unequal intensity or sound levels. The decibel, which is one-tenth of a bel, is the minimum change of sound level perceptible to the human ear. Hence, the decibel merely describes the ratio of two sound levels. A sound for which the power is 10 times as great as that of another sound level differs in power level by 1 bel, or 10 decibels. For example, 5 decibels may represent almost any volume of sound, depending on the intensity of the reference level or the sound level on which the ratio is based.

In sound system engineering, decibels are used to express the ratio between electrical powers or between acoustical powers. If the amounts of power to be compared are P1 and P2, the ratio in decibels (db) is

$$db = 10 \times \log \frac{(P2)}{(P1)}$$

(NOTE: When the logarithmic base is not indicated, it is assumed to be 10. The subjects of logarithms and logarithmic relationships are covered in Navy Training Course, Mathematics, Vol. 2, NavPers 10071-A.)

If P2 is greater than P1, the decibel value is positive and represents a gain in power. If P2 is less than P1, the decibel value is negative and represents loss in power.

INTENSITY LEVEL.—An arbitrary zero reference level is used to accurately describe the loudness of various sounds. This zero reference level is the sound produced by 10^{-16} watts per square centimeter of surface area facing the source. This level approximates the least sound perceptible to the ear and is usually called the threshold of audibility. Thus, the sensation experienced by the ear when subjected to a noise of 40 decibels above the reference level would be 10,000 times as great as when subjected to a sound that is barely perceptible.

ACOUSTICAL PRESSURE.—Typical values of sound levels in decibels and the corresponding intensity levels are summarized in table 5-4. The values in this table are based on an arbitrary zero reference level. Note that for each tenfold increase in power, the intensity of the sound increases 10 decibels. The power intensity doubles for each 3-decibel rise in sound intensity.

POWER RATIO.—The decibel is used to express an electrical power ratio, such as the gain of an amplifier, the output of a microphone, or the power in a circuit compared to an arbitrary reference power level. The value of decibels is often computed from the voltage ratio SQUARED or the current ratio SQUARED. These are proportional to the power ratio for equal values of resistance. If the resistances are not equal, a correction must be made.

To find the number of decibels from the voltage ratio, assuming that the resistances are equal, substitute E^2 for P in the basic equation:

Table 5-4.—Values of sound levels.

Sound level (decibels)	Intensity level (watts/cm^2)
0	10^{-16}
60	10^{-10}
80	10^{-8}
100	10^{-6}
110	10^{-5}
120	10^{-4}
130	10^{-3}

$$db = 10 \times \log \frac{E2^2}{E1^2} = 10 \times \log \left(\frac{E2}{E1}\right)^2$$

$$db = 20 \times \log \frac{E2}{E1}$$

To find the number of decibels from the current ratio, assuming that the resistances are equal, substitute I^2 for P in the basic equation:

$$db = 10 \times \log \left(\frac{I2}{I1}\right)^2$$

$$db = 20 \times \log \frac{I2}{I1}$$

The power level of an electrical signal is often expressed in decibels above or below an arbitrary power level of 0.001 watt (1 milliwatt) as

$$dbm = 10 \times \log \left(\frac{P}{0.001}\right)$$

where dbm is the power level above one milliwatt in decibels, and P is the power in watts.

The volume level of an electrical signal comprising speech, music, or other complex tones is measured by a specially calibrated voltmeter called a volume indicator. The volume levels read with this indicator are expressed in "v units" (vu), the number being numerically equal to the number of decibels above or below the reference volume level. Zero vu represents a power of 1 milliwatt dissipated in an arbitrary load resistance of 600 ohms (corresponds to a voltage of 0.7746 volt). Thus, when the vu meter is connected to a 600-ohm load, vu readings in decibels can be used as a direct measure of power above or below 1 milliwatt. For any other value of resistance the following correction must be added to the vu reading to obtain the correct vu value:

$$\text{vu} = \text{vu reading} + 10 \times \log \frac{600}{R}$$

where vu is the actual volume level, and R is the actual load, or resistance, across which the vu measurement is made. If the volume levels are indicated in units other than vu, the meter calibration, or reference level, must be stated with the decibel value.

CHAPTER 6

SERVOSYSTEMS

There are many types of servosystems in use, such as electronic, hydraulic, and amplidyne. There are also many different variations and combinations of these basic types. It is beyond the scope of this training manual to describe all systems in detail, since each servosystem is designed for a specific task. Therefore, the applicable manual should be referred to for each specific system.

It is recommended that the basic theory of synchros and servomechanisms as discussed in Basic Electricity, NavPers 10085-B, and Synchro, Servo, and Gyro Fundamentals, NavPers 10105, be reviewed before proceeding in this manual.

BASIC SERVOMECHANISMS

The essential components of a servomechanism are the data transmission system, the servocontrol amplifier, and the servomotor. These components are shown in the block diagram of figure 6-1 and are discussed in the following paragraphs.

The functions of the data transmission system are as follows:

1. To measure the servo output.
2. To transmit or feedback the signal, which is proportional to the output, to the error detector (a differential device for comparing two signals).
3. To compare the input signal with the feedback signal to the servo.
4. To transmit to the servoamplifier a signal which is proportional to the difference between the input and output signals.

The signal obtained by comparing the servo input and output is called the servo error, and is represented by the symbol E. Figure 6-1 shows that the servo error (E) is the difference between the input (θ_i) and the output (θ_o). This is stated mathematically as $E = \theta_i - \theta_o$.

In many servosystems the physical location of the servo input device and output device are remotely located from each other and may also be remotely located from the servoamplifier. This requires some means of transmitting the output information back to the device receiving

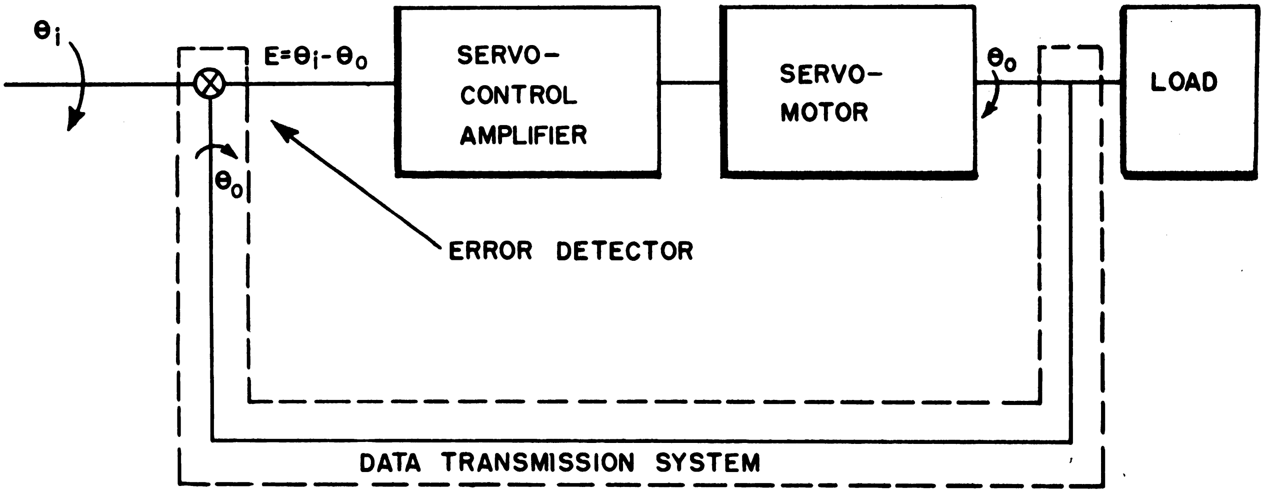

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Figure 6-1.—Simplified block diagram of a servomechanism.

the input command. This transmission system as well as the comparing device (called an error detector) is part of the data transmission system.

The function of the servoamplifier is to receive the error signal from the error detector, amplify it sufficiently to cause the output device to position the servo load to the commanded position, and to transmit the amplified signal to the servomotor.

The servomotor functions to position the servo load. The motor must be capable of positioning the load so as to require a minimum response time based on the requirements of the system.

ERROR DETECTORS

The component of the data transmission system that compares the input with the servomechanism output is the error detector. An error detector can be either a mechanical or an electrical device. A simple form of a mechanical error detector is the differential. However, in aircraft weapons systems, most error detectors are electrical devices because of their adaptability to widely separated or remotely installed components. Most of the electrical devices used are of either the potentiometer (resistive) or one of several magnetic devices.

Electrical error detectors may be either a-c or d-c devices depending upon the requirements of the servosystem. An a-c device used as an error detector must compare the two input signals and produce an error signal of which the phase and amplitude will indicate both direction and amount of control necessary for correspondence. A d-c device differs in that the polarity of output error signal determines direction of the correction necessary.

Error detectors are also used extensively in gyro stabilized platforms and rate gyros. In the stabilized platform, synchros are attached to the gimbals. Thus, any movement of the platform around the gyro axes is detected by the synchro and the error voltage is sent to the appropriate servosystem.

In rate gyros, the E-transformer (discussed later) is commonly used to detect gyro precession. It is extremely sensitive to very slight changes, but its movement is limited to a very small amount. Thus, it is extensively used with constrained gyros.

POTENTIOMETER

Potentiometer error detector systems are generally used only where the input and output of the servomechanism has limited motion. They are characterized by high accuracy, small size, and the fact that a d-c or an a-c voltage may be obtained as the output. Their disadvantages include limited motion, a life problem resulting from the wear of the brush on the potentiometer wire, and the fact that the voltage output of the potentiometer changes in discrete steps as the brush moves from wire to wire. A further disadvantage of some potentiometers is the high drive torque required to rotate the wiper contact.

An example of a balanced potentiometer error detector is shown in figure 6-2. As stated above, the purpose of the circuit is to give an output error voltage which is proportional to the difference between the input and output signals.

The command input shaft is mechanically linked to R1 and the load is mechanically linked to R2. An electrical source of 115 volts a.c. is applied across both potentiometers.

When the input and output shafts are in the same angular position, they are in correspondence and there is no output error voltage. If the input shaft is rotated, moving the wiper contact of R1, an error voltage is applied to the control amplifier. This error voltage is the difference of the voltages at the wiper contacts of R1 and R2. The output of the amplifier causes the motor to rotate both the load and the wiper contact of R2 until both voltages are equal; thus there is no output error voltage.

Figure 6-2 illustrates R1 and R2 grouped together. In actual practice the potentiometers may be positioned remotely from each other, with R2, the output potentiometer, being located at the output shaft or load. This remote location of one of the components does not remove it from being a part of the error detector.

E-TRANSFORMER

A type of magnetic device which is used as an error detector is the E-transformer. Its application is useful in systems that do not require the error detector to move through large angles. A simplified drawing, which is one of several possible devices in this category, is shown in figure 6-3.

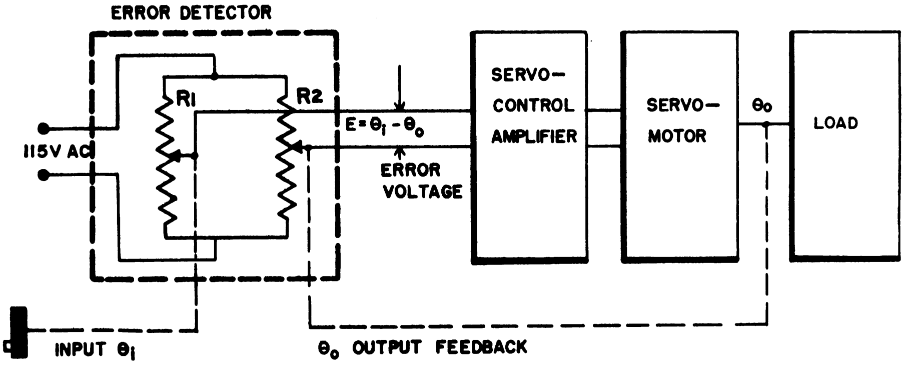

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Figure 6-2.—Balanced potentiometer error detector system.

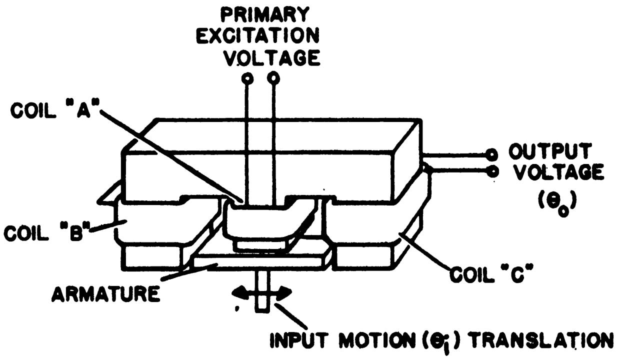

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Figure 6-3.—E-transformer error detector.

The primary excitation voltage is applied to coil A on the center leg of the laminated core. The coupling between coil A and the secondary windings, coils B and C, is controlled by the armature which is displaced linearly by the input signal. At the position of the armature where the coupling between the windings is balanced, the output voltage is minimum because of the series-opposing connections of the secondary windings. The phase of the output voltage on either side of the voltage null differs by 180°, and by proper design of the transformer the amplitude can be made proportional to the displacement of the armature from its null voltage position. This type of error detector possesses the advantages of small size and high accuracy, but has the disadvantage of permitting only limited input motion.

CONTROL TRANSFORMER

Synchros have been developed to a point of relatively high accuracy, low noise level, reasonably small driving torques, and excellent life. These qualities are also applicable to the synchro control transformers. A primary advantage over other types of error detectors is its unlimited rotation angle; that is, both the input and the output to the synchro control transformer may rotate through unlimited angles. Among the disadvantages of synchros (including the synchro control transformer) are the large size necessary to maintain high accuracy, the power consumed, and the fact that the output supplied to the servocontrol amplifier is always a-c modulated with the servo error.

It has been assumed so far that all electrical signals were direct-current signals. Alternating current may also be used if the two following conditions are met:

1. The frequency of the a.c. used must be greater than the maximum frequency response of the measuring devices used.
2. If negative values of the variables are allowed, the devices used must be phase-sensitive.

Figure 6-4 shows a d-c signal and the same function represented by an a-c voltage. The instantaneous value of the a-c signal does not indicate the value of the function, but the average value of the a-c signal may be used to represent the value of a function. If the a-c signal is the input to a servo motor, for example, the motor must not attempt to follow every variation of the a-c signal, but must follow the average value. The second condition is essential

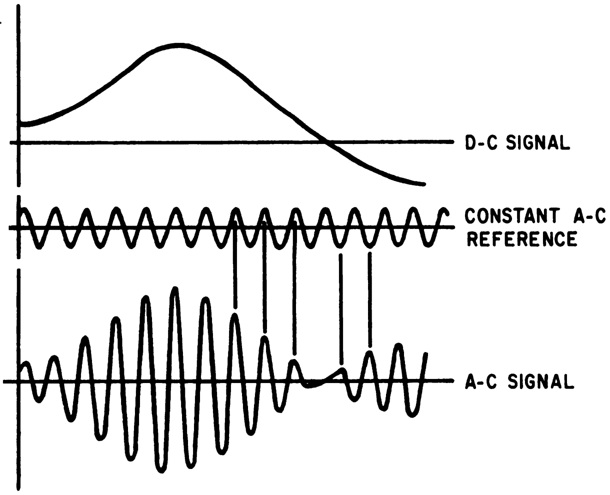

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Figure 6-4.—A-C modulated with the servo error.

because a negative a-c signal does not exist. However, negative values can be indicated by a change in phase of the signal. Note that in figure 6-4, during the period when the d-c signal is positive, the positive peaks of the a-c signal correspond to the positive peaks of the a-c reference; but during the period when the d-c signal is negative, the positive peaks of the a-c signal correspond to the negative peaks of the reference; i.e., the signal is 180° out of phase with the reference. A-C servomotors, which will rotate in one direction when the input signal is in phase with a reference voltage and in the other direction when the signal is out of phase with the reference voltage, are available.

The synchro data transmission system is comprised of a synchro transmitter, a synchro control transformer, and in some cases a differential transmitter for additional servo inputs. The synchro transmitter transforms the motion of its shaft into electrical signals suitable for transmission to the synchro control transformer, which comprises the error detector. (See fig. 6-5.)

The stator of the transmitter consists of three coils spaced 120 electrical degrees apart. The voltage induced into the stator windings is a function of the transmitter rotor position. These voltages are applied to the three similar stator windings of the synchro control transformer. The voltage induced in the rotor of the synchro control transformer depends upon the relative position of this rotor with respect to the direction of the stator flux.

The variation of the synchro control transformer output voltage as a function of the rotor position relative to an assumed stator flux direction is shown in figure 6-6. While there are two positions of the rotor, 180° apart, where the output voltage is zero, only one corresponds to a stable operating position of the servo.

In cases where a synchro differential transmitter is used for additional inputs to the servosystem, it is connected between the synchro transmitter and the synchro control transformer. (See fig. 6-7.) When the synchro differential rotor is in line with its stator windings, the differential transmitter acts as a one-to-one

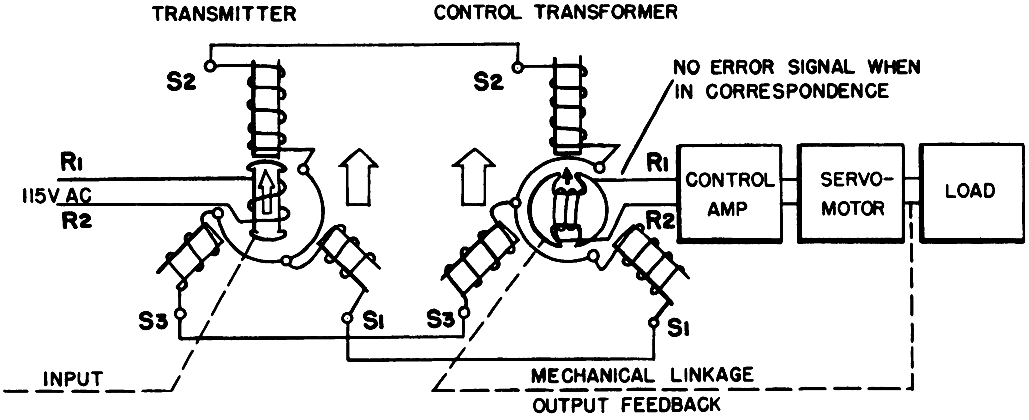

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Figure 6-5.—The control transformer as an error detector.

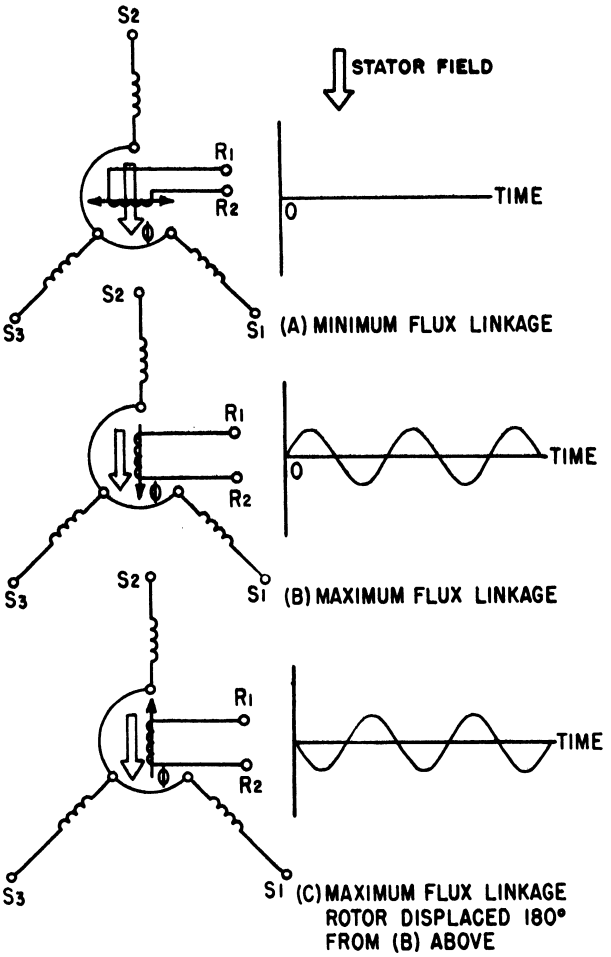

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Figure 6-6.—Induced voltage in synchro control transformer rotor.

ratio transformer and the voltages applied to the synchro control transformer are the same as the voltages from the synchro transmitter. If the synchro differential transmitter rotor is displaced by a second input, the voltages from the synchro transmitter to the control transformer are modified by the synchro differential transmitter by the amount and direction of its rotor displacement. Thus, the two inputs are algebraically added and fed to the synchro control transformer as a single input.

Magnetic error detectors are not limited to E-transformers and synchro devices.

A fluxgate element may be used to drive or excite a control transformer and is usually used in compass systems. The fluxgate operates on the principle of using the earth's magnetic field to produce a second harmonic current flow in the element which in turn produces a voltage in the stator windings of the control transformer that is in direct proportion to earth's magnetic north. Because it is desirable to use only the horizontal component of the earth's field, a gyro is used to hold the element level with the earth's surface, or the element is suspended by a spring and utilizes the properties of a pendulum to maintain a horizontal position. The assembly is rigidly mounted to the aircraft and turns in a azimuth as the aircraft turns.

MULTIPLE-SPEED DATA TRANSMISSION SYSTEMS

The static accuracy (how accurately the load is controlled) of a servomechanism is frequently limited only by the accuracy of the data transmission system. The accuracy of the data transmission system may be increased considerably by employing a multiple-speed data transmission system along with the single-speed system. The error-detector elements of the multiple-speed transmission system rotate at some multiple of the shaft being controlled, while the elements of the single-speed transmission system operate one-to-one with respect to the controlled shaft.

The schematic diagram of a multiple- and single-speed system is shown in figure 6-8. If the input shaft turns through 1° in this example, the single-speed transmitter also is rotated 1° while the multiple-speed unit is rotated 10°. The synchro control transformer associated with each of these transmitters is geared in similar ratios with respect to the servo output shaft. A 1° error between the position of the input and outputs shafts therefore produces a relative rotor displacement of 1° in the single-speed synchros and 10° in the multiple-speed synchros. If the relation between the rotor displacement and output voltage is linear, the error signal from the multiple-speed system is 10 times that from the single-speed system. This amplification of the error signal in the data transmission link reduces the signal amplification required in the servocontroller. If the synchro has an inherent error of 0.1° with respect to its own shaft, the consequent servo error introduced by a single-speed data transmission system will be of

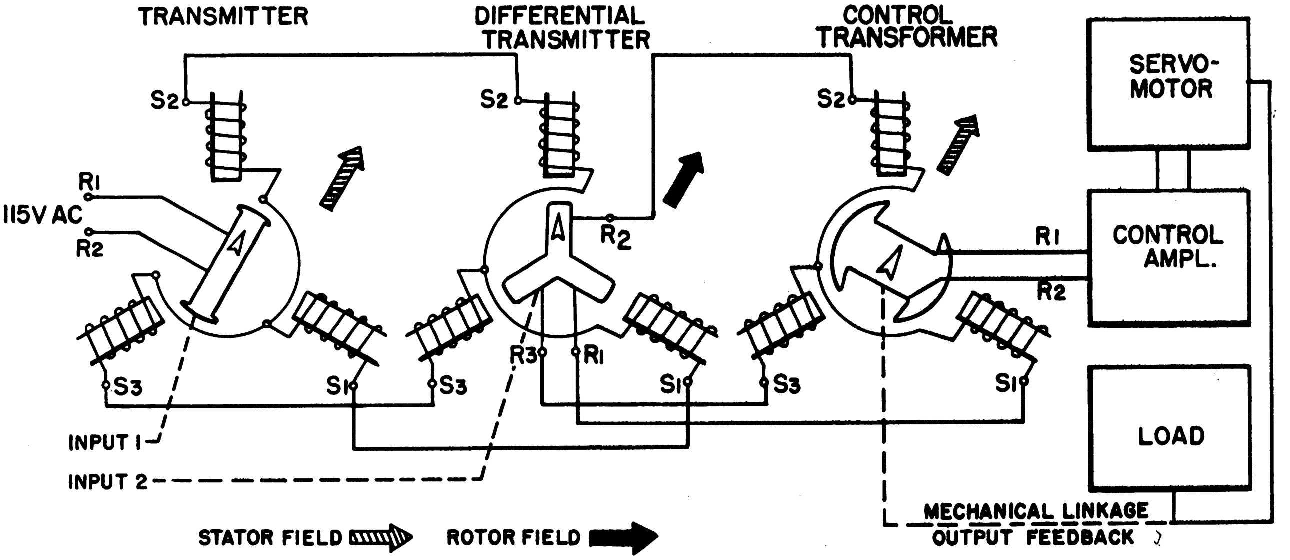

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Figure 6-7.—Synchro differential transmitter used for additional input.

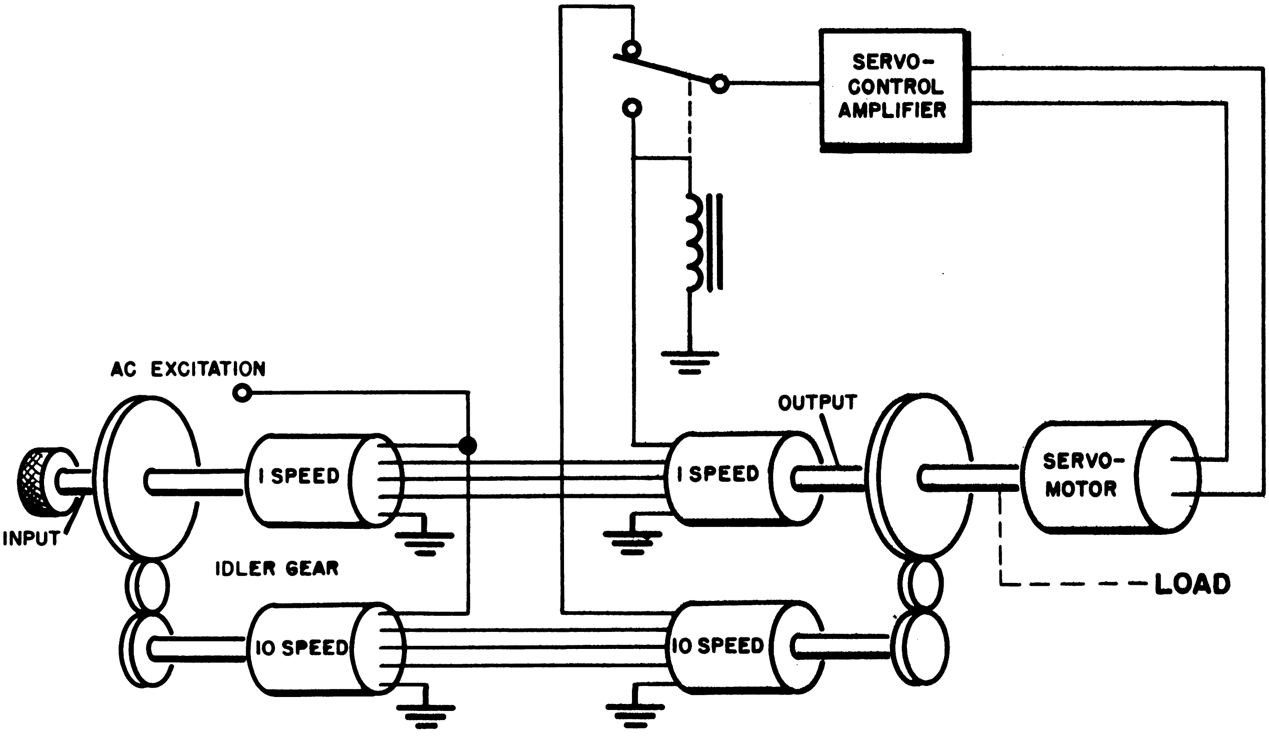

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Figure 6-8.—Multiple-speed data transmission system.

corresponding magnitude, but the consequent servo error introduced by a 10-speed data transmission system will be only one tenth as great, or 0.01°.

A disadvantage of using a multiple-speed error detector lies in the possibility of the system falling out of step and synchronizing in a position differing from the correct position by an integral number of revolutions of the multiple-speed synchro. In the example shown in figure 6-8, if the output shaft were held fixed and the input shaft rotated 36°, the 10-speed synchro transmitter would turn one complete revolution. At this point the error signal from the multiple-speed error detector would be zero. If the output shaft were then released, the system would operate in a stable fashion with a 36° error between the input and output shafts. The purpose of using a single-speed error detector along with the multiple-speed detector is to prevent this ambiguous synchronization.

An error signal selector circuit is provided which switches control of the servo to the single-speed data transmission system whenever the servo error becomes large enough to permit the multiple-speed system to synchronize falsely.

The simplest device imaginable that could control an error-selector circuit is shown in figure 6-8. It is essentially a single-pole, double-throw relay actuated by the output of the single-speed error detector. The relay is shown in the deenergized position. When the output of the single-speed synchro is high, the relay is energized and the single-speed circuit controls the servomotor. When the output is low, the relay opens and the 10-speed synchro controls the circuit. Keep in mind that the synchro output is high only when there is a large error.

The relationship of the coarse (single-speed) synchro output and the fine (10-speed) synchro output is shown in figure 6-9 (A). The shaded portion represents the area where control can be switched from single-speed circuit to the 10-speed circuit. With the selector circuit shown, it is still possible to have a single ambiguous synchronizing point. This point is at the 180° position of the single-speed (coarse) synchro. At this point the single-speed (coarse) and 10-speed (fine) shafts are nulled (but are 180° out of phase) and control is switched to the 10-speed circuit.

One way of eliminating this false synchronization position is to drive the multiple-speed synchro at any odd multiple of the single-speed synchro. Figure 6-9 (B) shows the phase relationship of a single-speed and seven-speed system. Although there is still a null of both synchros at the 180° position of the single-speed synchro, their outputs are in phase. This position is an unstable one and the servo will not remain at this point.

The system illustrated in figure 6-8 is not found in operating equipment due partly to the load the relay places on the single-speed synchro. In actual practice, the relay could be

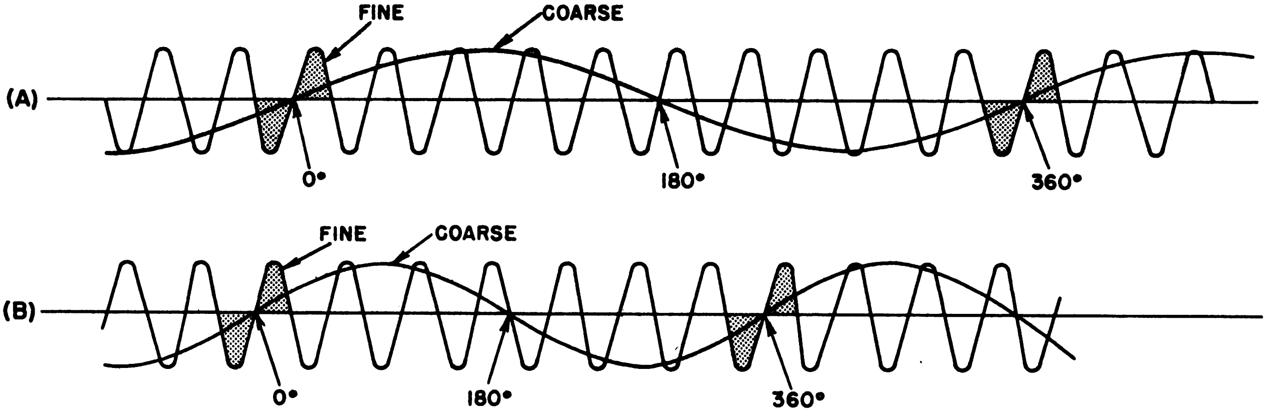

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Figure 6-9.—Phase relationships of fine and coarse synchro voltages; (A) single speed and 10 speed; (B) single speed and seven speed.

controlled by an electronic circuit operated by the synchro voltages. A method commonly used feeds the outputs of the synchros to an electronic circuit biased so that the fine-synchro voltage is not used when the coarse-synchro voltage is high. This method does not require a relay.

The disadvantage of using multiple-speed error detectors is the need of an additional synchro system and switching circuit if false synchronization is to be avoided. The increased servo accuracy resulting from the amplification of the error signal and the effective reduction of inherent synchro errors account for the wide use of these multiple-speed data transmission systems.

SERVOCONTROL AMPLIFIERS

In figure 6-2 the output of the error detector (error voltage) is fed to the servocontrol amplifier. This signal is small in amplitude and requires sufficient amplification to allow actuation of the prime mover. In addition to amplification, the servocontrol amplifier must, in some cases, transfer the error signal into suitable form for controlling the servomotor or output member. It may also include provisions for special characteristics necessary to obtain stable, fast, and accurate operation.

Servoamplifiers used in aircraft weapons systems are limited to electronic and magnetic types. The operation and explanation of electronic amplifiers and their circuits are covered in Basic Electronics.

In addition to the requirements of basic amplifiers, servoamplifiers must also meet certain additional requirements as follows:

1. A flat gain versus frequency response for a frequency well beyond the frequency range used.
2. A minimum of phase shift with a change in level of input signal. (Zero phase shift is desired but a small amount can be tolerated if constant.)
3. A low output impedance.
4. A low noise level.

Servoamplifiers may utilize either a-c or d-c amplifiers or in some instances a combination of the two. However, the application of d-c amplifiers is limited by such problems as drift and provisions for special bias voltages needed in cascaded stages. Drift, a variation in output voltage with no change in input voltage, can be caused by a change in supply voltage or a variation in value of a component. Consequently, many servoamplifiers utilize a-c amplifiers for voltage amplification. Amplifiers are discussed further in conjunction with other circuits later in the chapter.

MODULATORS

As pointed out previously, a-c amplifiers are more satisfactory for amplifying the error signal. They do not need well-regulated power supplies and costly precision components. However, some aircraft weapons systems utilize a d-c voltage for an error signal. The d-c error voltage may be changed to an a-c signal by the use of a modulator (sometimes called a chopper). Modulator circuits used in servocontrol amplifiers must be phase sensitive and produce an a-c output signal that is proportional to the d-c input signal in amplitude and the phase of it indicative of the polarity.

Vibrator Modulators

A modulator may be either an electromechanical vibrator or an electronic circuit. An example of a vibrator is shown in figure 6-10. An a-c supply voltage is employed to vibrate the contacts of the vibrator in synchronism with the supply voltage. The d-c error voltage is applied to the center contact of the vibrator. Assume that the reference voltage will cause the center arm to contact point A during the first half cycle and point B during the second half cycle. The output is represented by waveform B if the error voltage is positive and by waveform C when the error voltage is negative.

ELECTRONIC MODULATOR

An example of an electronic modulator circuit is shown in figure 6-11. The circuit shown is a diode ring modulator and works by causing a changing current to flow through one-half of the primary of transformer T2 and then through the other half at a 400-hertz rate. Each half-cycle of changing current produces a half-cycle of sinusoidal output voltage. The phase of this output voltage compared to the 400-hertz carrier depends upon the direction of current through each primary half.

Diodes CR1 and CR4 are forward biased when the d-c control voltage is positive. Diodes CR2 and CR3 are forward biased when the d-c control voltage is negative.

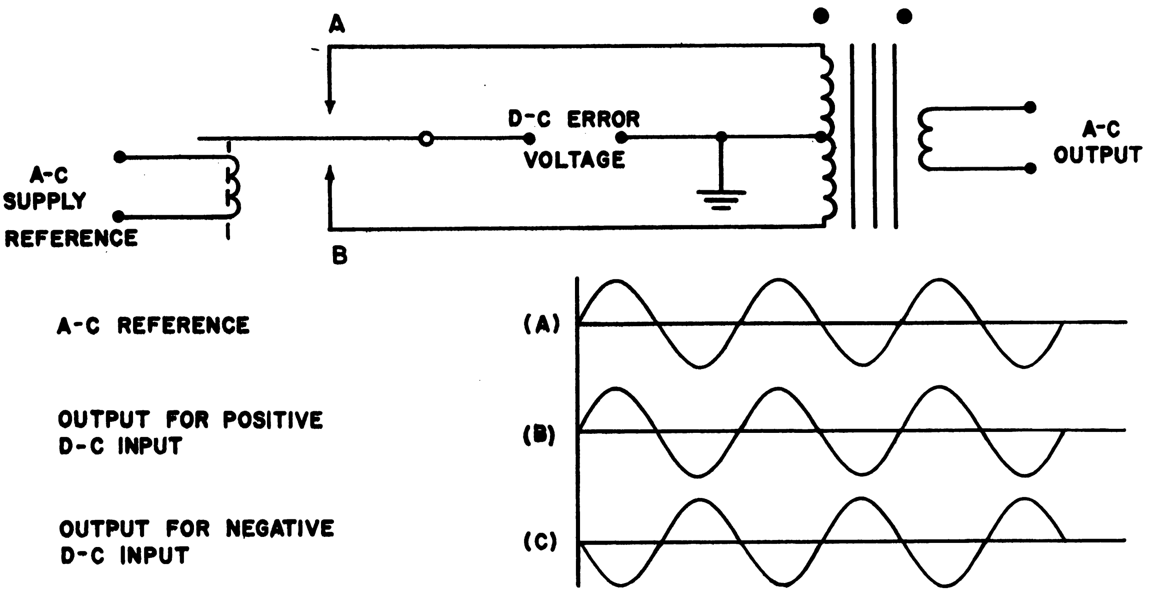

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Figure 6-10.—Vibrator modulator.

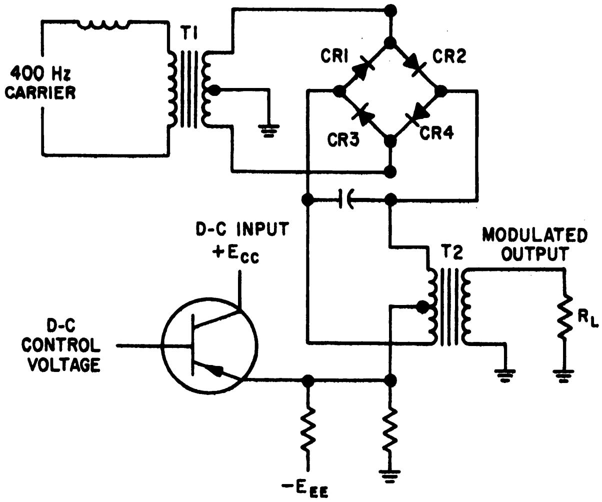

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Figure 6-11.—An electronic modulator.

Therefore, when two of the diodes are forward biased by the d-c control voltage, the other two are back biased and cut off. As long as the instantaneous amplitude of the carrier voltage is less than the d-c control voltage, the cutoff diodes remain back biased and the current flows through one of the conducting diodes and through one of the half windings.

When one of the back biased diodes becomes forward biased (the amplitude of carrier voltage exceeds the d-c control voltage), the diode conducts. This interrupts the current flowing through the half winding. The result is that the output voltage amplitude is clipped at the value it had when the current was interrupted.

The capacitor connected across the primary of T2 filters any high frequency components associated with the clipped half-cycle of the sine wave so that a nearly sinusoidal output half-cycle occurs. The output's amplitude is approximately equal to the output voltage at the time of clipping.

The capacitor operates by coupling the high frequency components of the clipped voltage through the nonconducting half windings. The high frequency components are canceled because they produce currents which flow in opposite directions in both halves of the center tapped primary windings; that is, they produce magnetic fields which cancel each other.

Therefore, the amplitude of each half-cycle of the 400-hertz carrier voltage is modulated by the d-c control voltage. The polarity of the control voltage determines the phase of the modulated carrier voltage output relative to the unmodulated carrier voltage input. This is done as a result of the direction of current flow through the half winding. This direction depends upon which diode is forward biased as a result of the polarity of the d-c control voltage.

PHASE DETECTORS

In the preceding section of this chapter, it has been stated that the a-c amplifier has inherent advantages over the d-c amplifier, that a d-c error voltage can be changed into an a-c signal, and the a-c signal can be amplified and applied to an a-c servomotor. However, some systems utilize d-c servomotors which necessitates converting the a-c signal to d.c. To accomplish this, a phase detector, sometimes referred to as a demodulator, is used.

Figure 6-12 displays a phase detector using a bridge circuit. With no error input signal and only the reference voltage applied, CR1 and CR2 would conduct in series when point C is on its positive half-cycle. When point C is on its negative half-cycle, CR3 and CR4 would conduct in series. Assuming the drops across the diodes and resistances to be equal, points A and B would be at ground potential on both half-cycles and the output voltage would be zero.

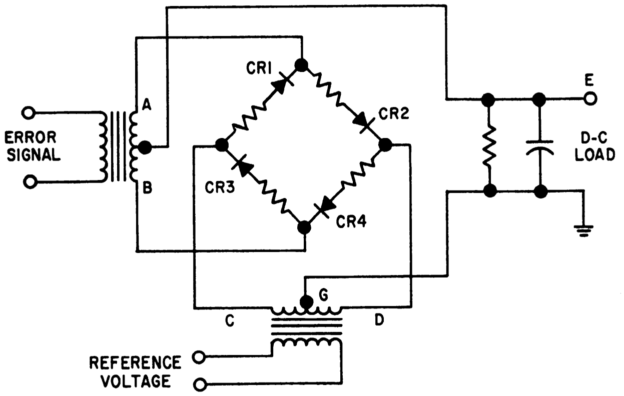

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Figure 6-12.—Bridge phase detector.

When an error signal is applied to the bridge in phase with the referenced voltage and points A and C are both on their positive half-cycle, electron flow will be from point G on the reference transformer T2, to point D, through CR2 to point A, from point A to the center tap on T1, and to E through R_L to G. On the next half-cycle, both points A and C will change polarity and the electron flow will be from point G to point C, through CR3 to point B, through T1 to the center tap, to the right to point E, and through R_L to G. On both half-cycles of reference and error voltage, the electron flow was down through R_L to ground, developing a negative d-c output voltage.

If the error signal is applied out of phase with the reference voltage and positive at points A and D, electron flow will be from point G up through R_L, left to the center tap of T1, down to point B, through CR4, down to point D, and left to point G. On the next half-cycle, both points A and D will have changed polarity; thus, electron flow will be from G up through R_L to the center tap of T1, up to point A, through CR1 to point C, and right to the center tap to point G. On both half-cycles of the error and reference voltages, electron flow was up through R_L, developing a positive voltage output at point E. The magnitude of the d.c. produced at point E in both instances was dependent on the amplitude of the a-c error signal and the polarity of the d.c. was dependent on the phase of the a-c error signal. C_L is used to filter the pulses and provide smooth d.c.

Triode Phase Detectors

A phase detector using triode tubes (fig. 6-13) also provides amplification of the error signal in addition to phase detection. In this circuit, as in the previous one, the plates of the tubes are supplied with the a-c reference voltage in such a manner that the plate voltages are in phase. For the purpose of explanation,

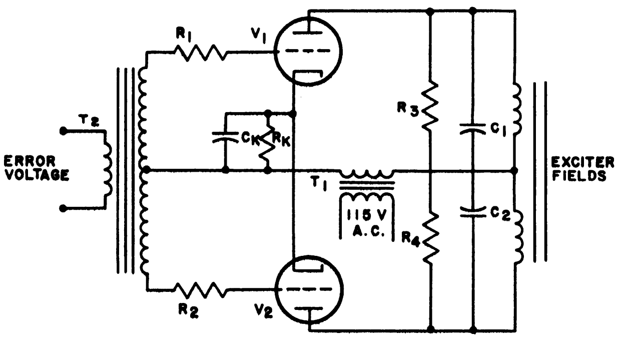

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Figure 6-13.—Triode phase detector.

assume that no error signal is present at T2. When the plates of V1 and V2 are positive, the two tubes conduct equally. The plate current that flows sets up magnetic fields in the d-c motor exciter windings that are equal and opposite; therefore, the fields cancel and produce no output. When the plate voltages are on a negative half cycle, C1 and C2 discharge through their respective exciter windings to maintain a constant direct current through the windings.

If an error signal is introduced into the primary of T2 with a phase relationship that causes the grid of V1 to be positive at the same instant that the plate of V1 is positive, the following conditions exist:

1. On this half cycle the conduction of V1 is increased above its no error signal condition.
2. The heavier plate current causes a stronger field to be created in the upper exciter winding.
3. At this same instant, since the grid of V2 is on a negative half cycle, its average conduction is reduced to a level below that of its no error signal condition.
4. The lower level of plate current causes a weaker field to be produced in the lower exciter winding.
5. Since the magnetic fields produced in the exciter windings are no longer of equal amplitude, they no longer cancel each other.
6. The exciter produces an output voltage of a polarity controlled by the polarity of the resultant field and of an amplitude controlled by the relative strength of this resultant field.
7. The exciter output causes the proper mechanical actions necessary to reduce the amplitude of the error to zero.
8. As the error signal is reduced to zero, the current conduction through V1 and V2 is again balanced. Also the exciter fields are equal and opposite, canceling each other, reducing the exciter output to zero, and stopping the mechanical action. Resistors R1 and R2 prevent excessive grid current when the error angle is large.

SPECIAL CIRCUITS

It has been shown how a servocontrol amplifier may have provisions for changing a d-c error signal to an a-c signal and how an a-c error signal may be detected to supply a d-c voltage to a servomotor or controller. In the following paragraphs other special amplifier circuits are discussed.

Two-Stage D-C Servocontrol Amplifier

If somewhat more power is required by the servomotor than can be supplied by the servoamplifier (fig. 6-13) a push-pull d-c amplifier can be inserted between the phase-sensitive triodes and the servomotor. In the schematic diagram (fig. 6-14), the output of the phase detector triodes is now taken across the parallel RC networks in the plate circuit.

The bias source, E_{cc}, for the d-c amplifier is connected with its positive terminal on the grid side. This positive voltage subtracts from the highly negative voltage across the capacitor to give a resulting negative voltage which allows the tube to operate on the linear portion of its characteristic curve.

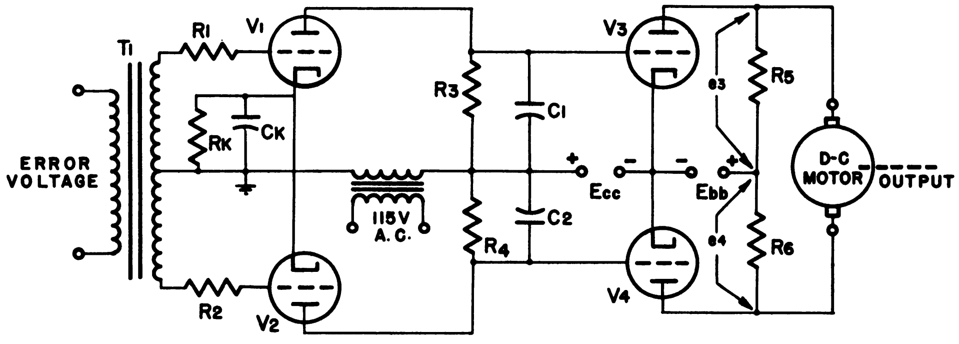

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Figure 6-14.—Two-stage d-c servocontrol amplifier.

When there is no signal input from the error detector, the plate currents of the phase-sensitive rectifiers are equal. The outputs of V1 and V2 are applied to the grids of V3 and V4, respectively. Equal output from V1 and V2 causes equal currents to flow in V3 and V4. With R5 and R6 equal in resistance and current, the voltage across the motor is zero. Consequently, the motor does not turn.

When there is a signal output from the error detector, the following action occurs. Assume that the error signal makes the grid of V1 positive and the grid of V2 negative. The plate current of V1 increases and the plate current of V2 decreases. An increasing plate current in V1 increases the charge on capacitor C1 and conversely a decreasing plate current in V2 decreases the charge on capacitor C2. As a result of this change in error signal, the voltage on the grid of V3 is now more negative than the voltage on the grid of V4. This increased negative voltage on the grid of V3 decreases its plate current and the voltage e3 decreases. The decreased negative voltage on the grid of V4 increases its plate current and the voltage e4 increases. As a result, a voltage difference appears across the motor armature and the motor rotates.

When the output signal from the error detector reverses in phase, the sequence of events that follow will cause the motor to reverse its direction of rotation.

Magnetic Amplifiers as Servocontrol Amplifiers

The servomotor used in conjunction with the magnetic amplifier shown in figure 6-15 is an a-c type. The uncontrolled phase may be connected in parallel with transformer T1 by utilizing a phase shifting capacitor, or it may be connected to a different phase of a multiphase system. The controlled phase is energized by the magnetic amplifier and its phase relationship is determined by the polarity of the d-c error voltage.

The magnetic amplifier consists of a transformer (T1) and two saturable reactors, each having three windings. Note that the d-c bias current flows through a winding of each reactor and the windings are connected in series-aiding. This bias current is supplied by a d-c bias power source. A d-c error current also flows through a winding in each reactor; however, these windings are connected in series-opposing.

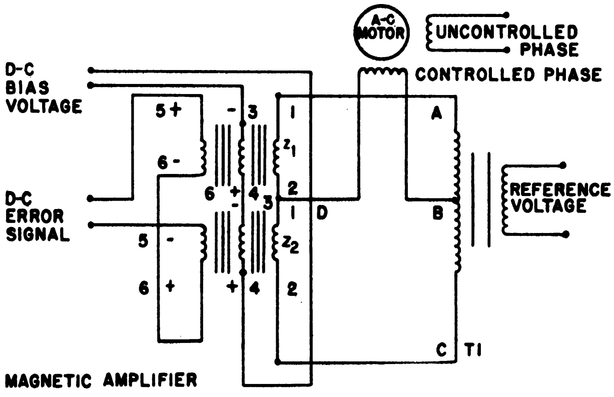

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Figure 6-15.—Magnetic amplifier servocontrol amplifier.

The reactors Z1 and Z2 are equally and partially saturated by the d-c bias current when no d-c error signal is applied. The reactance of Z1 and Z2 are now equal, resulting in points B and D being at equal potential. There is no current flow through the controlled phase winding.

If an error signal is applied causing the current to further saturate Z2, the reactance of its a-c winding is decreased. This current through Z1 tends to cancel the effect of the d-c bias current and increase the reactance of its a-c winding. Within the operating limits of the circuit, the change in reactance is proportional to the amplitude of the error signal. Hence, point D is now effectively connected to point C causing motor rotation. Reversing the polarity of the error signal causes the direction of rotation to reverse since point D is effectively connected to point A.

The basic magnetic servoamplifier discussed above has a response of approximately 6 to 20 Hz. In some applications this delay would be excessive, creating too much error. However, this delay can be reduced to about 1 Hz by using special push-pull circuits.

Amplifier Integrator

A servosystem in a steady state condition will have a constant positional displacement between input and output, which is called the error. The only way to reduce this error is to increase the drive torque. Thus, a new signal must be introduced that is related to the error. The error is not changing; therefore, it cannot be a derivative signal, nor can it be proportional to the error, because it would then decrease as the error decreases and a new condition would be met without removing the error. The only way left is to produce a signal proportional to the integral of the error. Then if a torque proportional to the time integral of the error is added to the normal torque which is proportional to the error, it can be seen that the error will eventually be reduced to zero. A circuit that is used for this purpose is called an amplifier integrator.

A simple and commonly used integrator consists of two circuit elements: a resistor and capacitor. (See fig. 6-16.) The voltage across the capacitor is proportional to the integral of the charging current. It can be explained by considering that the voltage across a capacitor is

$$E = \frac{Q}{C}.$$

For any given capacitor (C), the voltage depends directly on the charge (Q) which is the imbalance of electrons on the two capacitor plates. The amount of this charge depends on the current flow and the time which this flow exists.

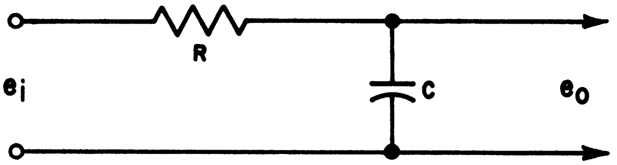

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Figure 6-16.—Simple integrator.

The fact that the voltage is proportional to the integral of the charging current allows the RC circuit to be used as an integrator. The capacitor voltage is the integrator output. Provision must be made to supply a charging current that is proportional to the input information. The purpose of the resistor is to produce this proportional current from an input signal voltage "e_i." At the instant this voltage is applied, the charging current becomes

$$i = \frac{e_i}{R}.$$

Unfortunately this proportionality does not continue to exist. As the capacitor becomes charged, the capacitor voltage opposes the charging current, and the charging current becomes less proportional to the input signal. This results in an error in the output. The ideal output, for a constant input signal is a steadily increasing output. This steady increase is attained only when the signal voltage is first applied and the capacitor has not become appreciably charged.

A remedy to this error in the RC integrator is to use a circuit with a long time constant. Such a circuit delays the charging of the capacitor. The result is a more accurate integration of an input signal. The ideal output would be a perfect triangular wave. Although a long time constant produces more accurate results, it also provides a much lower output for the same input signal. Better integration is possible by the use of a high gain, feedback amplifier.

An amplifier integrator is illustrated in figure 6-17. The circuit arrangement uses a high gain amplifier and is known as the Miller integrator. The amplifier produces an output which is not limited by the input signal as it is in the simple RC integrator. The amplifier also supplies any energy which is required in the output. The function of the input signal is to control the charging current.

The operation can be explained by assuming a constant input as shown in figure 6-17 (A). At the start, assume the initial condition is zero, that is,

$$e_i = e_g = e_o = 0.$$

Also assume that the capacitor is discharged. The positive voltage to be integrated, "e_i," is then applied. The capacitor charges with a polarity as shown, since electrons are attracted from the left plate. The charging path is shown in figure 6-17 (B).

A voltage measured at the amplifier input, "e_g," tends to rise in the positive direction since this point is directly coupled to "e_i." However, this rise tends to be opposed by the degenerative feedback voltage from the output. The output will be $-Ae_g\,(e_o)$. The letter "A" stands for the amplifier gain. The minus sign indicates that the out polarity or phase is opposite to the input. The output changes "A" times

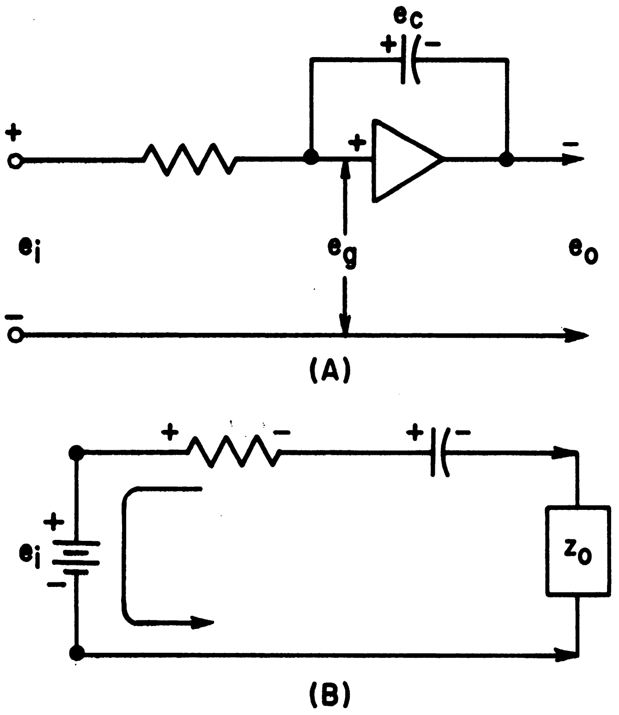

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Figure 6-17.—Amplifier integrator.

faster or steeper than "e_g." The output voltage is negative and aids the charging of the capacitor.

For a certain input voltage, the charging current is limited to a particular value which tends to keep "e_g" practically zero. If the current should exceed this value, "e_g" would decrease a small amount due to the increased voltage drop across R. Then e_o would decrease, and the charging current would decrease to the original value. If the initial charging current should decrease, the opposite action would occur. The value of the charging current is therefore stabilized to a specific value proportional to the input voltage. This eliminates the error caused by "e_i" and the charging current not remaining proportional in the fundamental RC integrator.

This constant charging current must be produced by "e_o" despite the fact that the steadily increasing capacitor voltage opposes the charging current. To do this, "e_o" must also steadily increase. This steady increase in "e_o" is exactly the integrator output voltage desired for a constant signal input.

Similar action would be produced for a condition in which the input signal suddenly became negative. Polarities then would be in reverse to those shown in the example given. Remember that simple examples are used for explanation on the assumption that the desired result also will be produced for a more complicated signal input. Removal of "e_i" would produce little effect upon the output which existed at that instant, since the amplifier output would oppose the tendency for the capacitor to discharge.

The limits for "e_o" are determined by the amplifier and not by "e_i" or the range of "e_g." The output range would be designed to produce an increasing output for any probable input amplitude and period of application. The exception to this would be an integrator which was designed to function also as a limiter.

OUTPUT DEVICES

The output of the servocontrol amplifier is fed to an output device. The functions of this device, usually a servomotor, are to supply torque, power, and dynamic characteristics required to position the servo load. Ideally, the power device should require small power from the control amplifier, accelerate rapidly, be of small size and weight, be of lasting endurance, have small time lags, and have an adequate speed range. In aircraft weapons systems, the electric motor is most frequently used as an output device. However, electromagnetic clutches, hydraulic devices, and pneumatic devices are also used.

ELECTRIC MOTORS

In aircraft weapons systems, electric motors are primarily used to drive the servo load. The type of electric motor used within a particular equipment is determined by power factors as type of power available, output power, speed range, inertia, and electrical noise.

Alternating-Current Motors

Alternating-current motors are frequently used in low power servo applications because of their simplicity, reliability, absence of commutator sparking, and rapid response. However, they have a disadvantage of having a narrow speed range characteristic. The theory of operation of a-c motors is discussed in Basic Electricity. However, this training manual briefly discusses the types of motors applicable to servosystems.

The 2-phase induction motor is the most widely used a-c servomotor. The stator of the motor consists of two similar windings which are positioned at right angles to each other. The rotor may be wound with short-circuited turns of wire or it may be a squirrel cage rotor. The squirrel cage rotor is the type most frequently encountered. It is made up of heavy conducting bars which are set into armature slots, the bars being shorted by conducting rings at the ends.

Two a-c voltages 90° out of phase must be applied to the stator windings in order for the motor to turn. These out-of-phase voltages generate a rotating magnetic field which induces a voltage in the rotor. This induced voltage generates a magnetic field in the rotor that is displaced 90° from the stator magnetic field. The interaction of these two magnetic fields causes the armature to rotate.

As stated previously, the voltage to the two stator windings must be 90° out of phase to cause the rotor to turn. The direction of rotation is determined by the phase relationship of the stator windings which, in turn, is determined by the servo error detector. One phase is connected directly to one of the stator windings while the other phase is used to energize an error detector. The resulting error voltage is either in phase or 180° out of phase with the signal applied to the error detector. This will cause the controlled phase to either lead or lag the uncontrolled phase by 90°.

Most induction motors have low starting torque and high torque at high speed. For servo applications, it is desirable to have high starting torque in order that the system may have a low time lag. This may be accomplished by increasing the armature resistance with the use of materials such as zinc for the conducting bars. This increased torque at low speed results in decreased torque at high speed. However, increased stability of the servosystem is a desirable result of this change.

Split-phase a-c motors are similar to the 2-phase induction motor. It differs only in that a phase shifting network is used to shift the phase of the voltage supplied to one of the windings by 90°. This is usually accomplished by connecting a capacitor in series with the uncontrolled winding of the stator. Direction of rotation and reversal is accomplished in the same manner as in the 2-phase motor discussed above.

Other types of motors that may be used with an a-c power supply are shaded pole, universal, and repulsion motors. They utilize various methods of obtaining rotation reversal. However, they are seldom found in aircraft weapons systems.

Direct-Current Motors

Direct-current motors have an advantage of having higher starting torque, reversing torque, and less weight for equal power than a-c motors.

Series motors are characterized by their high starting torque and poor speed regulation with a change in torque. Higher torque can be obtained on reversal of direction with a series motor than any other type. However, it is a unidirectional motor and requires special switching circuits to obtain bidirectional characteristics. This is normally done by switching either the armature or field connections but not both.

A variation of the series motor that has bidirectional characteristics is the split-series motor. The motor has two field windings on its frame, only one of which is used for each direction of rotation. This reduces the number of relay contacts required for reversing by one-half. This double winding also reduces the torque capabilities of the motor as compared to a straight-series motor wound on the same frame.

The most frequently used d-c servomotor is the shunt motor. Its direction of motion is controlled by varying the direction of flow of either the armature or field current. The uncontrolled current is usually maintained constant to preserve a linear relationship between the motor output torque and the voltage or current input. The field windings are usually two differentially wound coils to facilitate direction control of the field current by the servocontrol amplifier. The field current is usually controlled with receiving type vacuum tubes. The larger armature currents require thyratrons or generators as current regulators but are not normally found in aircraft weapons systems.

MAGNETIC CLUTCHES

Any device utilizing an electrical signal that may be used to control the coupling of torque from an input shaft to an output shaft is a magnetic clutch. This coupling may be accomplished by the contact between friction surfaces or by the action of one or more magnetic fields. A magnetic clutch is used only to couple the input torque to the output shaft. Thus, it is capable of controlling large amounts of power and torque for its size and weight. The magnetic clutch may be used with a large flywheel driven at high speed by a small motor. This allows the flywheel to impart very large acceleration to the load when the magnetic clutch is energized.

There are two distinct types of magnetic clutches. Some transmit torque by physical contact of frictional surfaces. Others utilize the action of magnetic flux produced by two sets of coils or one set of coils and induced eddy currents resulting from rotating the one set of coils near a conducting surface. The eddy current type of clutch offers smoother operation and has no problem of wear, due to friction. Both types have suitable control characteristics and are found in servomechanisms.

HYDRAULIC DEVICES

Hydraulic components used in servomechanisms are frequently found in aircraft weapons systems. Hydraulic power devices, such as motors and associated control valves, have an advantage of a response much faster than the best electric motors and equal to that of a magnetic clutch system. They also require a minimum of maintenance, have very high accuracy, and are well adapted to heavy loads.

The essential components of a hydraulic system are:

1. Source of high pressure oil and sump to receive discharge oil.
2. Control valve and means of employing an actuating signal.
3. Actuator (motor or cylinder).

The theory of operation of a hydraulic system is discussed in Fluid Power, NavPers 16193-B.

The source of high pressure oil serves as a source of power to operate the actuator. However, this source of power is controlled by the control valve. This valve is actuated by the output from the servocontrol amplifier. This control is normally accomplished by feeding the error signal to a solenoid controlled valve. However, the error signal could be used to drive an electric motor which, in turn, actuates the control valve. The actuator is usually in the form of an axial motor which must be a reversible and variable speed type. Some applications may employ a cylinder where linear motion is required for positioning.

SERVOMECHANISM OSCILLATION

In aircraft weapons systems, servomechanisms are utilized for various functions and must meet certain performance requirements. These requirements not only concern such things as speed of response and accuracy, but the manner in which the system responds in carrying out its command function. All systems contain certain errors, the problem being to keep them within the allowable limits.

As discussed previously, the servomotor must be capable of developing sufficient torque and power to position the load in a minimum of time. The servomotor and its connected load have sufficient inertia to drive the load past the point of command position. This overshooting results in an opposite error voltage, reversing the direction of rotation of the servomotor and the load. The servomotor again attempts to correct the error and again overshoots the point of correspondence with each reversal requiring less correction until the system is in correspondence. The time required for the oscillations to die out determines the transient response of the system and can be greatly reduced by the use of damping.

DAMPING

The function of damping is to reduce the amplitude and duration of the oscillations that may exist in the system. The simplest form of damping is viscous damping. Viscous damping is the application of friction to the output load or shaft that is proportional to the output velocity. The amount of friction applied to the system is critical and will materially affect the results of the system. When just enough friction to prevent overshoot is applied, the system is said to be critically damped. When the friction is greater than that for critical damping, the system is overdamped. However, when damping is slightly less than critical, the system is said to be slightly underdamped, which is usually the desired condition. The application of friction absorbs power from the motor and is dissipated in the form of heat.

A pure viscous damper would absorb an excessive amount of power from the system. However, a system having some of the characteristics of a viscous damper with somewhat less power loss is used in actual practice. The first of this type of damper to be discussed utilizes a dry friction clutch to couple a weighted flywheel to the output drive shaft. A flywheel has the property of inertia which may be defined as that property of matter by which it will remain at rest or in uniform motion in the same straight line or direction unless acted upon by some external force.

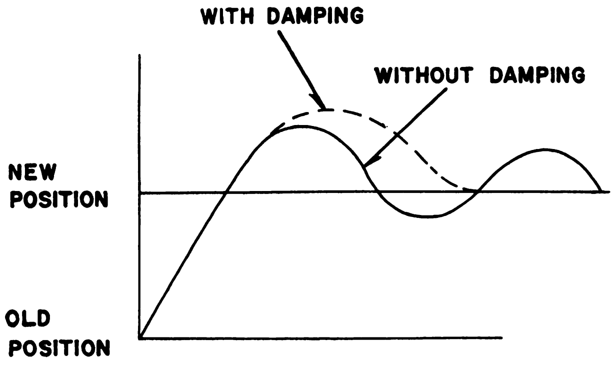
However, since the flywheel is coupled to the output shaft with a friction clutch, any rapid change in velocity of the output member causes the clutch to slip. This slipping effectively disconnects the flywheel instantaneously but allows sufficient power to be coupled to the flywheel to overcome its inertia. As the inertia is gradually overcome, the flywheel gains speed and approaches the velocity of the output member. As the point of correspondence is neared and the error signal is reduced, the inertia of the flywheel gives up power to the system, causing the load to increase its overshoot. When the system attempts to correct for this overshoot, the inertia of the flywheel adds to the output load, reducing the effect of the correcting signal. This effect dampens the oscillations in the system, reducing its transit time.

Another type of damper used is the eddy current damper. This damper utilizes the interaction of induced eddy currents and a permanent magnet field to couple the output shaft to a weighted flywheel.

The effect of damping is shown in figure 6-18. The solid line shows the action of the load without damping. The time required to reach a steady-state condition without damping should be noted. This time is greatly reduced although the initial overshoot is increased.

As shown in figure 6-18, viscous dampers effectively reduced transient oscillations, but it also produced an undesired steady-state error.

How well the load is controlled is a measure of the steady state performance of a servosystem. If the load is moved to an exact given position, then the servosystem is said to have perfect steady state performance. If the load is not moved to the exact position, then the system is not perfect and the difference in error is expressed as the steady state error. Steady state error may be either one or both of the following: velocity lag or position error. Velocity error is the steady state error due to viscous drag during velocity operation. Position error is the difference in position between the load and the position order given to the servosystem. Since the friction damper absorbs power from the system, its use is normally limited to small servo-mechanisms.

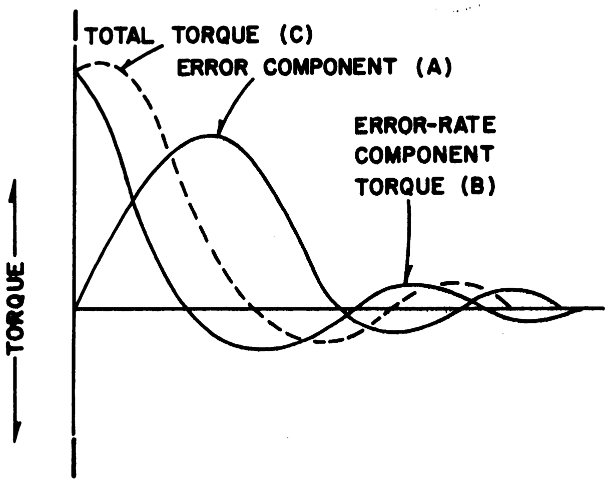


AT.248

Figure 6-18.—Effect of friction damper.

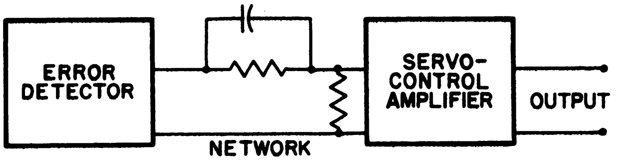
To overcome the disadvantages of the viscous dampers and still provide damping, error-rate damping is used. This type of damping consists of introducing a voltage that is proportional to the rate of change of the error signal. This voltage is fed to the servocontrol amplifier and combined with the error signal. Figure 6-19 shows the effect of error-rate damping on the torque output of the servomotor. Curve A shows the torque resulting from the error voltage; curve B shows the torque resulting from the error-rate damper; and curve C depicts the resultant of curves A and B. It should be noted that torque resulting from the damper increases the total torque as long as the error component is increasing. Once the error component starts to decrease, the error-rate damper produces a torque in an opposite direction reducing the transit time of the system.

There are two methods of generating an error-rate voltage normally found in aircraft weapons systems. They are the tachometer and electrical networks. The tachometer error-rate damper utilizes a device which is essentially a generator having an output voltage proportional to its shaft speed. The tachometer is connected to the shaft of the output member giving a voltage proportional to its speed. The output voltage is fed to a network that modifies this voltage so that it is proportional to a change in input voltage. This voltage is fed back to the servocontrol amplifier and added with the error signal as shown in figure 6-18.



AT.249
Figure 6-19.—Torque variations using error-rate damping.

Electrical networks used for error-rate damping consist of a combination of resistors and capacitors used to form an RC differentiating network. For a detailed explanation of RC circuits, refer to Basic Electricity. These networks, sometimes referred to as phase advance or lead networks, vary in design, depending on the type of error signal. However, in practice, networks are normally limited to the d-c type. (See fig. 6-20.) This is because of the unstable results that would be caused by a small change in frequency of the power source. An a-c system may utilize a d-c network by first using a demodulator (detector) prior to the network. However, the output of the network must be modulated for use in the remainder of the a-c system. Like the tachometer, the output of the network is fed to the servocontrol amplifier.



AT.250
Figure 6-20.—Error-rate stabilization network.

INTEGRAL CONTROL

Servomechanisms used in aircraft weapons systems are sometimes required to follow an input function, the magnitude of which changes at a constant rate with time, such as an antenna system tracking a target. This, if the input is the angle of a shaft, the velocity of the shaft may be constant for a substantial percentage of time. The servomechanism may be required to respond to this type of input with substantially zero error. The error that characterizes the servo response to a constant velocity input is known as the velocity error.

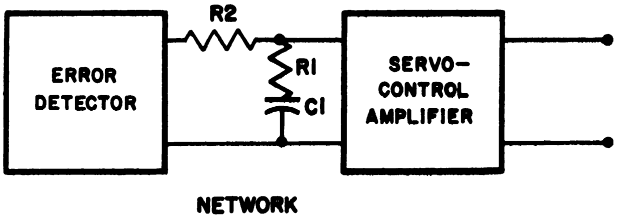
To correct for velocity error or an inaccuracy due to a steady-state error, an integral control may be used. This control modifies the error voltage in such a manner that the signal fed to the servocontrol amplifier is a function of both the amplitude and time duration of the error signal. This is accomplished by the use of a variable voltage divider whose output would increase with time for a constant input. As in all voltage dividers, the output is only a portion of the input which effectively reduces the amplitude of the error signal. To compensate for this loss of amplitude, additional amplification must be used either in the form of a preamplifier or a higher gain servocontrol amplifier. With the overall gain of the system now increased to give a normal output for transient error signals, small velocity or steady-state error signals of long duration will result in somewhat increased output to the servomotor due to the action of the integral control.

The integral control (fig. 6-21) consists of a combination of resistors and capacitors connected to make an integrator circuit for a d-c error signal. The value of the components are such that the capacitor does not have sufficient time to change with fluctuations in error voltage. Only that portion of the transient error signal developed across R1 is impressed on the amplifier. However, with a velocity error or steady-state error of longer duration, the capacitor (C1) charges, increasing the amplitude of the amplifier input.

Networks shown in figure 6-21 are not limited to d-c systems as a demodulator may be used prior to the integrator and its output modulated for easier amplification.

GAIN, PHASE, AND BALANCE

The overall system gain has a most important effect on the servomechanism response



AT.251
Figure 6-21.—Integral stabilization network.

characteristics and is one of the more easily adjustable parameters in electronics servocontrollers. Increasing the system gain reduces the system velocity errors and those steady-state errors resulting from restraining torques on the servo load or misalinement in the system. An increase in system gain also increases the speed of response to transient inputs. However, excessive gain always decreases the rate at which oscillatory transients disappear, and continue increase in the system gain eventually produces instability.

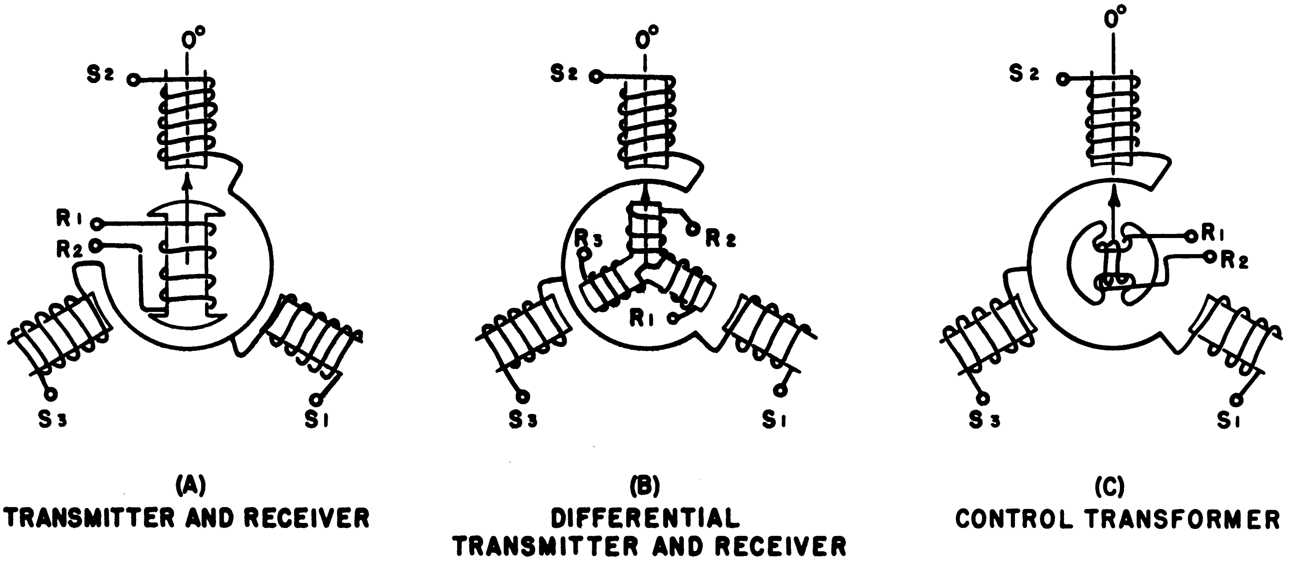
Servosystems using push-pull amplifiers must be balanced to insure equal torque in both directions of the servomotor. This adjustment should be checked periodically as a change in value of a component may cause an unbalanced output. Balancing is accomplished by adjusting the system for zero output with no signal applied.

A phase control is included in some servosystems using a-c motors. The two windings of the a-c servomotor must be energized by a-c signals that are 90° apart. A phasing adjustment is normally included in the system to compensate for any phase shift in the amplifier circuit resulting in unstable operation of the system. This adjustment may be located in the control amplifier, or in the case of a split-phase motor, it may be in the uncontrolled winding.

ZEROING SYNCHRO UNITS

In this chapter the importance of accuracy of servomechanisms has been stressed. In any servomechanism using synchro units, it is also very important that the units be zeroed electrically.

For a synchro transmitter or receiver to be in a position of electrical zero, the rotor must be alined with S2, the voltage between S1 and S3, as shown in figure 6-22 (A), must be zero, and the phase of the voltage at S2 must be the same as the phase of the voltage at R1.



(A)
TRANSMITTER AND RECEIVER

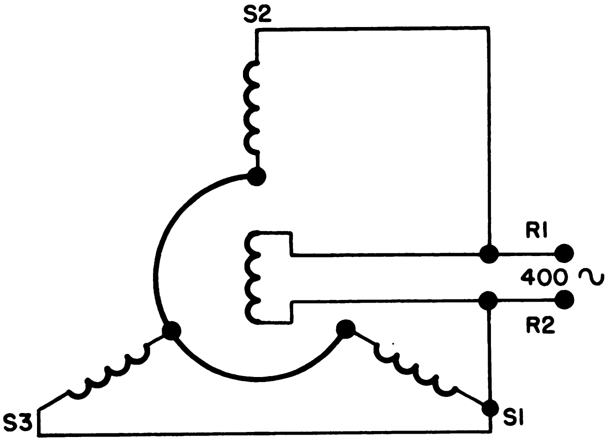
(B)
DIFFERENTIAL
TRANSMITTER AND RECEIVER

(C)
CONTROL TRANSFORMER

AT.252
Figure 6-22.—Synchro electrical zero positions.

TRANSMITTERS AND RECEIVERS

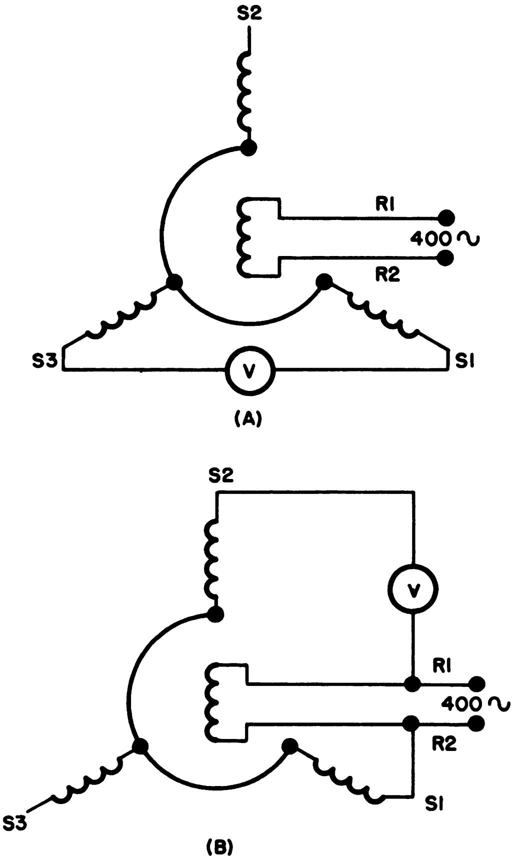
The most common methods of zeroing synchro transmitters and receivers are the a-c voltmeter method and the electrical lock method. The method used to zero a synchro depends upon how the synchro is used. Where the rotor is free to turn the electrical lock method can be used. This is accomplished by connecting S1 and S3 to R2 using a jumper wire and connecting S2 to R1. (See fig. 6-23.) When power is applied, the rotor will position itself in the zero position. After the synchro is zeroed, the pointer is adjusted to indicate zero.



AT.253

Figure 6-23.—Electrical lock method of zeroing a synchro.

Possibly the great majority of synchros used in aviation weapons systems have their rotors gear driven or mechanically coupled to a driving member. In these cases it is necessary to use the a-c voltmeter method, zeroing the synchro by rotating the stator or housing until its electrical zero is reached. Before zeroing the synchro, the mechanical unit that positions the synchro must be set to its indexing or ZERO position. This is done by alining the unit to its index and installing its indexing pins in the holes provided for this purpose. The pins hold the unit to its index and keep it from moving.



AT.254

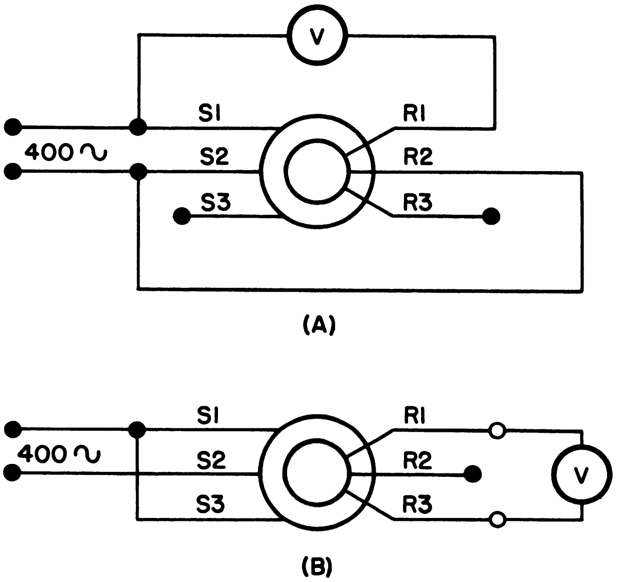
Figure 6-24.—A-c voltmeter method of electrically zeroing synchro receiver or transmitter.

The a-c voltmeter method is done by connecting the meter and jumper wires as shown in (A) of figure 6-24. Rotate the energized synchro until a zero reading is obtained on the voltmeter. Since rotor positions of zero degree and 180° produce this zero reading, it is necessary to determine if the phase of S2 is the same as that of R1. Make the connections as shown in (B) figure 6-24. If the proper polarity relationship exists, the voltmeter indicates less than the excitation voltage being applied to the rotor. If the indication is greater than the rotor excitation voltage, the rotor (or starter) must be rotated 180° and the previous step must be performed again.

Differential Transmitter

The. electrical zero position of a synchro differential transmitter or receiver is when the three windings of the rotor are in correspondence with their respective stator windings and their respective voltages are in phase. (See fig. 6-22 (B).)

Because the differential transmitter synchro is normally used to insert a correction into a synchro system, it is usually driven either directly or through a gear train. Before zeroing the differential transmitter synchro, the unit whose position the differential synchro transmits should first be zeroed. After this has been accomplished, connect the differential synchro as shown in figure 6-25 (A). Turn the synchro in its mounting until the voltmeter shows a minimum indication. After completing this step, make the connections shown in figure 6-25 (B). Again turn the synchro slightly in its mounting, until a minimum voltage is indicated by the voltmeter.



(A)

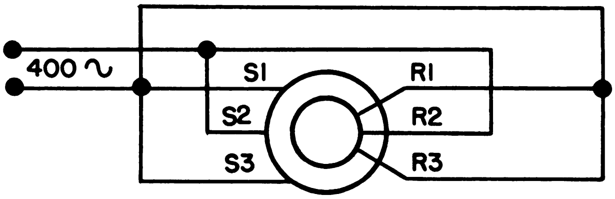
(B)

AT.255
Figure 6-25.—Electrically zeroing a differential transmitter.

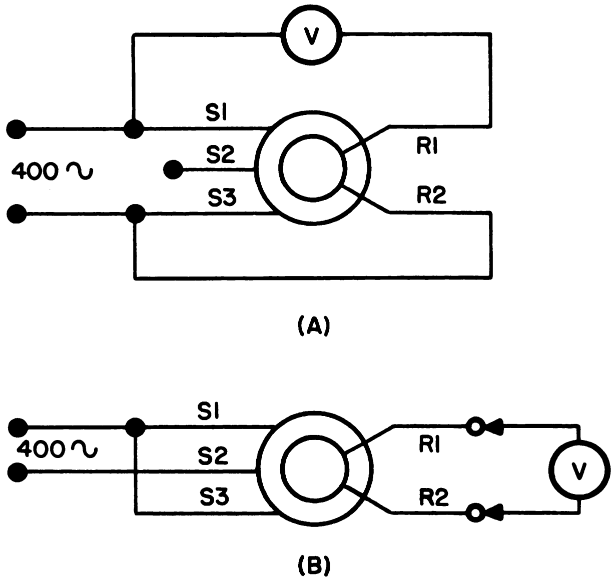
Differential Receiver

Electrical zero for a differential receiver is illustrated in figure 6-22 (B). To zero a differential receiver synchro, make the connections shown in figure 6-26. As soon as the power is applied to the synchro, the rotor assumes a position of electrical zero. The dial can then be set at zero and the unit reconnected to its circuit.

The synchro control transformer is normally zeroed by using the a-c voltmeter method. It should be remembered that the electrical zero position of the control transformer is 90° from that of a receiver since the rotor winding must be perpendicular to the stator's resulting magnetic field to have a zero output. (See fig. 6-22 (C).) The coarse adjustment is made by connecting the meter and unit as shown in figure 6-27 (A). The rotor is rotated to give a minimum or null reading on the voltmeter. The final adjustment is made by connecting the unit as shown in figure 6-27 (B) and displacing the rotor a few degrees in both directions to determine the null or electrical zero position. Once the zero position has been determined, the unit must be locked as discussed previously.



AT.256
Figure 6-26.—Electrically zeroing a differential synchro receiver.



(A)

(B)

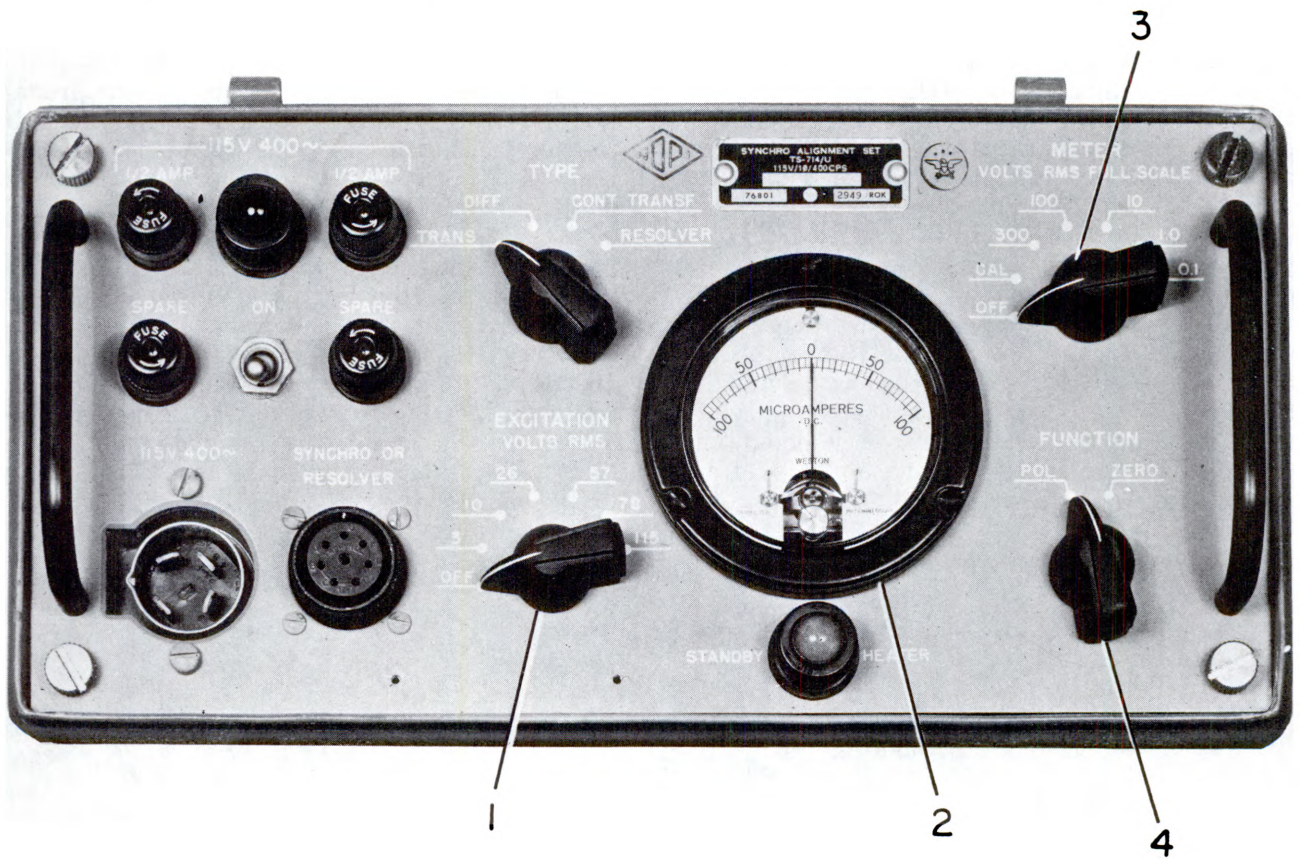
AT.257
Figure 6-27.—Electrically zeroing a control transformer synchro.

SYNCHRO ALIGNMENT SET TS-714/U

The Synchro Alignment Set TS-714/U (fig. 6-28) is a portable, general purpose test set used to check the alinement of synchros or resolvers. It can be used to aline any 400 Hz synchro or resolver. In addition to its higher sensitivity, the test set has an additional advantage over the methods previously discussed in that the test set can also supply excitation voltage for the synchro or resolver being alined.

The test set basically consists of a bandpass amplifier and power supply, a synchro or resolver excitation supply with outputs from 3 to 115 volts rms (1, fig. 6-28) and switching circuits. The output voltages from the synchros or resolvers are applied to the amplifier, the output of which is fed to a phase sensitive detector circuit. The detector's output is metered by the microammeter (2). A meter switch (3) selects the meter sensitivity from 300 volts full scale to 0.1 volt full scale, plus a calibrate and off position.

The meter has a ZERO center scale and indicates 0 when the synchro or resolver is adjusted to either of its two nulls. The synchro or resolver is adjusted to a null position with the function switch (4) in the ZERO position. When the null is reached, the function switch is switched to the POL position and note is taken of the meter reading. Then the function switch is returned to ZERO position and the synchro is rotated 180° to its opposite null. When the opposite null is reached, the function switch is again switched to the POL position and a note made of the reading. The correct null will be



AQ.364

1. EXCITATION VOLTS RMS switch.
2. MICROAMMETER.
3. METER switch.
4. FUNCTION switch.

Figure 6-28.—Synchro Alignment Set TS-714/U front panel.

the one indicating the lowest reading with the function switch in the POL position. When the synchro is adjusted to this null, it is electrically zeroed with the correct polarity.

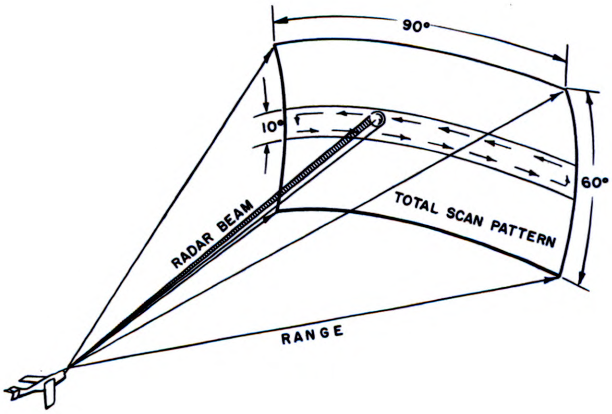
For detailed instructions on the use of the TS-714/U, consult Operation and Service Instruction Manual, NA 11-70-FAG-510.

ANTENNA POSITIONING SERVOSYSTEM

In this section the application of a servomechanism to position a radar antenna and supply target information to the weapons system is discussed. However, before discussing the servosystem, consider the scan pattern of a typical aviation fire control radar.

The antenna radiator and reflector form a conical pattern of circular symmetry with beam dimensions as shown in figure 6-29. The antenna assembly contains a spinner motor that rotates the beam about the antenna axis to produce a 7° conical scan. While the radar is in the search mode of operation, the rotating cone scans both horizontally and vertically, covering an area of 10° vertically by 90° horizontally. (See fig. 6-30.) The search pattern may be positioned vertically from a positive 30° to a negative 30° by the antenna positioning lever.

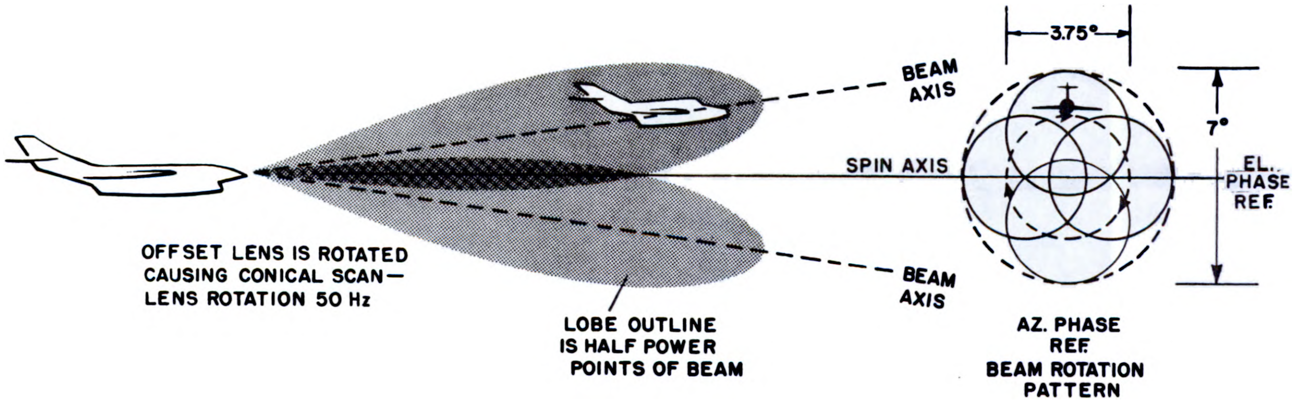
The operator normally observes the targets, identifies each as friend or foe, and determined which target, if any, to pursue. Since the antenna utilizes its 7° conical pattern only during track operation, some means must be provided for positioning the antenna on the selected target to begin the track operation. This is accomplished by bracketing the selected target with strobe lines. When the target has been selected and bracketed, a lock-on switch is depressed, positioning the antenna on the predetermined target and placing the equipment in the automatic track mode of operation. The antenna is now positioned by the radar receiver output, keeping the target centered in the 7° beam.



AQ.366

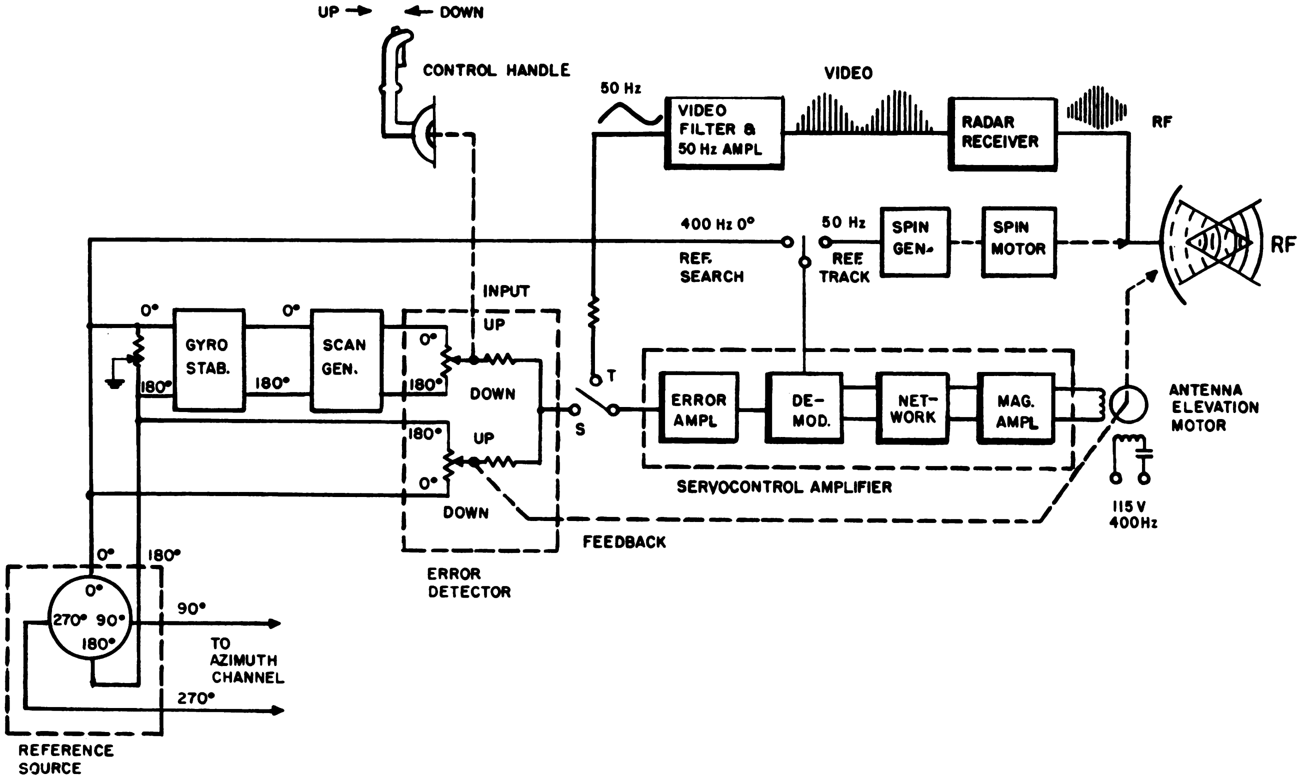
Figure 6-30.—Typical antenna scan pattern.

A block diagram of a typical fire control antenna servosystem is shown in figure 6-31. It should be noted that the azimuth channel of the antenna control system has been omitted, as its operation is similar to the elevation channel. Since the antenna servosystem utilizes different components during search and track operation, the system used in each mode of operation is discussed separately.


3.75°
BEAM AXIS
7°
SPIN AXIS
EL. PHASE REF.
OFFSET LENS IS ROTATED CAUSING CONICAL SCAN— LENS ROTATION 50 Hz
LOBE OUTLINE IS HALF POWER POINTS OF BEAM
BEAM AXIS
AZ. PHASE REF.
BEAM ROTATION PATTERN

AQ.365

Figure 6-29.—Antenna beam with conical scan.



AQ.367

Figure 6-31.—Antenna elevation servosystem functional block diagram.

SEARCH OPERATION

The main components of the antenna servosystem used during search operation are:

1. Error detector and its a-c voltage source.
2. Servoamplifier.
3. Servomotor.
4. Data transmission system.

The a-c generator supplies voltage to the input and feedback potentiometers of the balanced potentiometer error detector. However, the voltage fed to the input potentiometer is fed through a gyro space stabilizer and scan generator.

The function of the gyro space stabilizer is to cause the antenna to scan a selected area 90° horizontally and 10° vertically, regardless of any roll or pitch of the aircraft. As in all fire control equipment of this type, the amount of correction that can be made by the gyro space stabilizer is limited by the limit of the radar scanner. The output of the gyro space stabilizer is an a-c voltage, the amplitude of which is a function of the roll and pitch of the aircraft. The principles of operation of gyros are discussed later in this manual.

The function of the vertical scan generator is to automatically position the antenna in the vertical geometric plane. Referring to figure 6-30 note that the antenna scans horizontally and vertically. The scan generator provides the necessary voltage change to cause the antenna to change its angle of elevation by 3° when the antenna reaches its azimuth limits.

The error detector has three inputs that are summed and compared against the antenna's position. The gyro space stabilizer and scan generator constitute two inputs by controlling the amplitude of the voltage supplied to the input potentiometer. The third input is the control handle which positions the wiper contact of the input potentiometer. The output of the error detector is an a-c voltage whose amplitude and phase is determined by the voltages on the wipers of the potentiometers.

The error signal is fed to the servoamplifier where it is amplified and compared with the phase of the reference voltage. The phase of the output voltage causes the servomotor to rotate in a direction reducing the error voltage.

The data transmission system is the mechanical linkage necessary to drive the wiper of the feedback potentiometer, indicating the actual position of the antenna in the vertical plane at all times.

TRACK OPERATION

The main components of the servosystem employed during track operation are:

1. Radar receiver and 50-Hz amplifier.
2. Servoamplifier.
3. Servomotor.
4. 50-Hz spin generator.

The radar receiver functions as the error detector, supplying a 50-Hz error voltage. Before discussing the other components of the system, first determine how the receiver provides the error signal. As stated previously, the antenna axis is centered approximately on a target prior to going into track operation. The antenna is rotating at 50 revolutions per second while the radar transmitter is transmitting a pulse of energy 450 times per second. When the antenna axis is pointing directly at the target, the target return and receiver video output remain at a constant level. However, if the target were above the antenna axis as shown in figure 6-32, the amplitude of the video would vary as the antenna rotated about its axis. It should be noted that the video amplitude is maximum when the beam axis is at its highest elevation and minimum when the beam axis is at its lowest elevation. The video output from the receiver is filtered, leaving only the 50-Hz envelope to be employed as an error voltage.

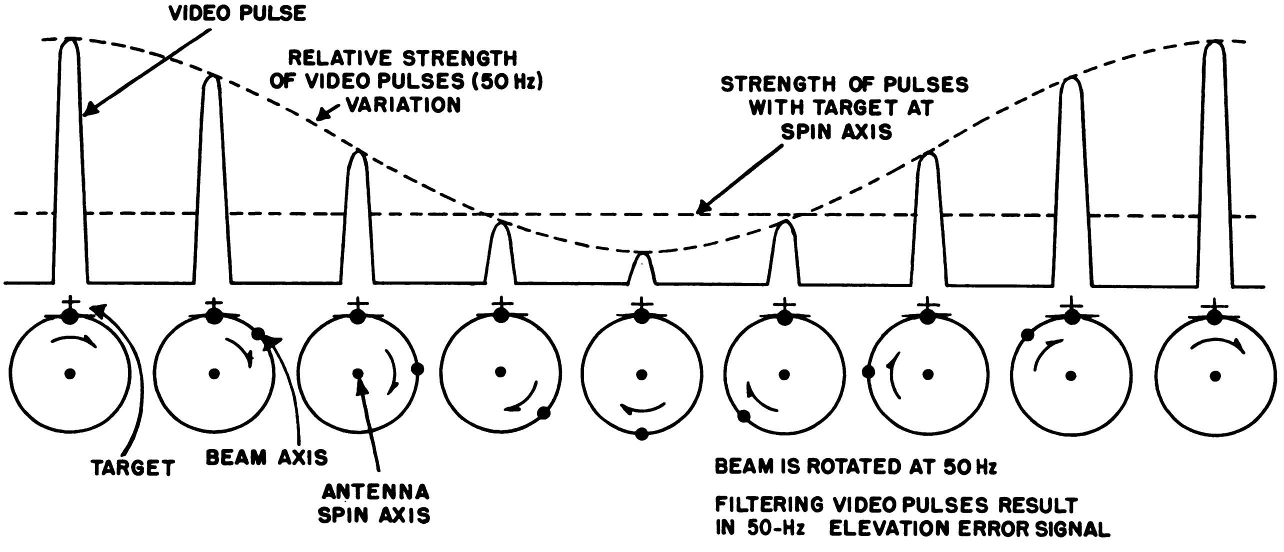
The function of the servoamplifier is to amplify the 50-Hz error voltage and compare its phase with the phase of the 50-Hz reference voltage originating in the 50-Hz spin generator. The phase of the output voltage to the servomotor causes the motor to rotate in the direction which reduces the amplitude of the error signal.

THEORY OF SEARCH OPERATION

The schematic diagram of the antenna servosystem described above is shown in figure 6-33 (A) and (B). As in the case of the block diagram, the system's search mode of operation is discussed first.

Scan Generator

The elevation scan generator is utilized during automatic search only. It consists of two resistors and one double-pole relay. Since only one resistor is in the circuit at a time, they serve alternately to unbalance the voltage applied to the error-detector potentiometer R3. The input to the scan generator is an a-c voltage


VIDEO PULSE
RELATIVE STRENGTH OF VIDEO PULSES (50 Hz) VARIATION
STRENGTH OF PULSES WITH TARGET AT SPIN AXIS
+
TARGET
BEAM AXIS
ANTENNA SPIN AXIS
BEAM IS ROTATED AT 50 Hz
FILTERING VIDEO PULSES RESULT IN 50-Hz ELEVATION ERROR SIGNAL

AQ.368

Figure 6-32.—Derivation of elevation error signal.

with its center point grounded by a resistor network. With both R1 and R2 shorted, the center of R3 would also be at ground potential. Inserting R1 in the circuit would cause the center of R3 to be at some potential just as though the wiper of R3 had been moved to the right. Shorting R1 and inserting R2 would have the same effect as moving the wiper of R3 to the left.

The relay is actuated by a cam attached to the azimuth limit mechanism; the cam operates when the antenna reaches either azimuth limit.

Error Detector

The balanced potentiometer error detector consists of potentiometers R3 and R35. Potentiometer R35 is supplied with a 400-Hz reference voltage of approximately 32 volts amplitude while the reference voltage applied to R3 is modified as discussed above. This voltage source is center tapped and grounded, thus reflecting an apparent ground at approximately the center of each potentiometer. A control handle displacement causing a change in the wiper contact of R3 results in an unbalanced voltage condition with an error signal being fed to the search contact of relay K2. With the equipment on search, the error signal is applied to the servoamplifier.

Servoamplifier

The servoamplifier consists of the following stages:

1. Preamplifier.
2. Phase shifter amplifier.
3. Amplifier.
4. Demodulator driver.
5. Demodulator.
6. Cathode followers.
7. Search/track network.
8. Magnetic amplifier drivers.
9. Magnetic amplifier.

Preamplifier V1 receives the error voltage from relay K2 and amplifies it. The preamplifier output is coupled through C1 to the grid of V2 and to the relay K3.

Phase shifter amplifier V2 is bypassed during search operation and is discussed under track operation.

Amplifier V3 provides an additional stage of amplification of the error signal. Its output is coupled through C4 to the gain control R15. The gain control determines the amplitude of the error signal fed to the demodulator driver. Thus, the gain of the antenna servosystem is controlled by R15.

The demodulator driver provides the final amplification of the error signal prior to demodulation. As pointed out above, the amplitude of the signal applied to the grid can be controlled by the gain potentiometer (R15). The gain of the stage is stabilized by degenerative feedback. The feedback is accomplished by two means, an unbypassed cathode resistor R22 and a plate-to-grid feedback loop consisting of C5, C6, and R17. In addition to gain stabilization, the plate-to-grid loop provides the characteristic of an error-rate damper.

The full-wave demodulator employs the use of two dual triodes, V5 and V6. Its operation is somewhat similar to that of a triode demodulator. The input error signal from the demodulator driver is applied to either the plate or cathode of the demodulator triodes. The reference voltage, which is 400 Hz during search operation, is supplied to the grids through either T1 or T2 with the primary-secondary phase relationship as shown in figure 6-33. (NOTE: The small black rectangles on the input and output leads of the transformers in figure 6-33 are polarity marks. Instantaneous voltage polarity at the transformer primary polarity mark corresponds to the same polarity at the secondary polarity mark.)

Figure 6-34 shows a synchrogram of the voltages existing in the demodulator. It should be noted that when the error signal and reference voltage are in phase, V5A conducts on the first half-cycle and V6A conducts on the second half-cycle. Since V5B is cut off during the time V5A is conducting, V5A draws electrons from the top plate of C8, charging it positive. During the second half-cycle, electrons flowing through V6A are deposited on the lower plate of C9, giving it a negative charge. This action results in a push-pull output being supplied to the cathode followers.

When the error signal is 180° out of phase with the reference voltage, V5B and V6B conduct on alternate half-cycles, charging C8 and C9 to the opposite polarity.

The cathode followers, V7 and V8, isolate the d-c output of the demodulator from the low impedance of the search network. (See fig. 6-33 (B).) Potentiometer R25 is provided to balance the outputs of V7 and V8 when no error signal is present.

The search/track network consists of two RC band-pass filter networks which have fairly

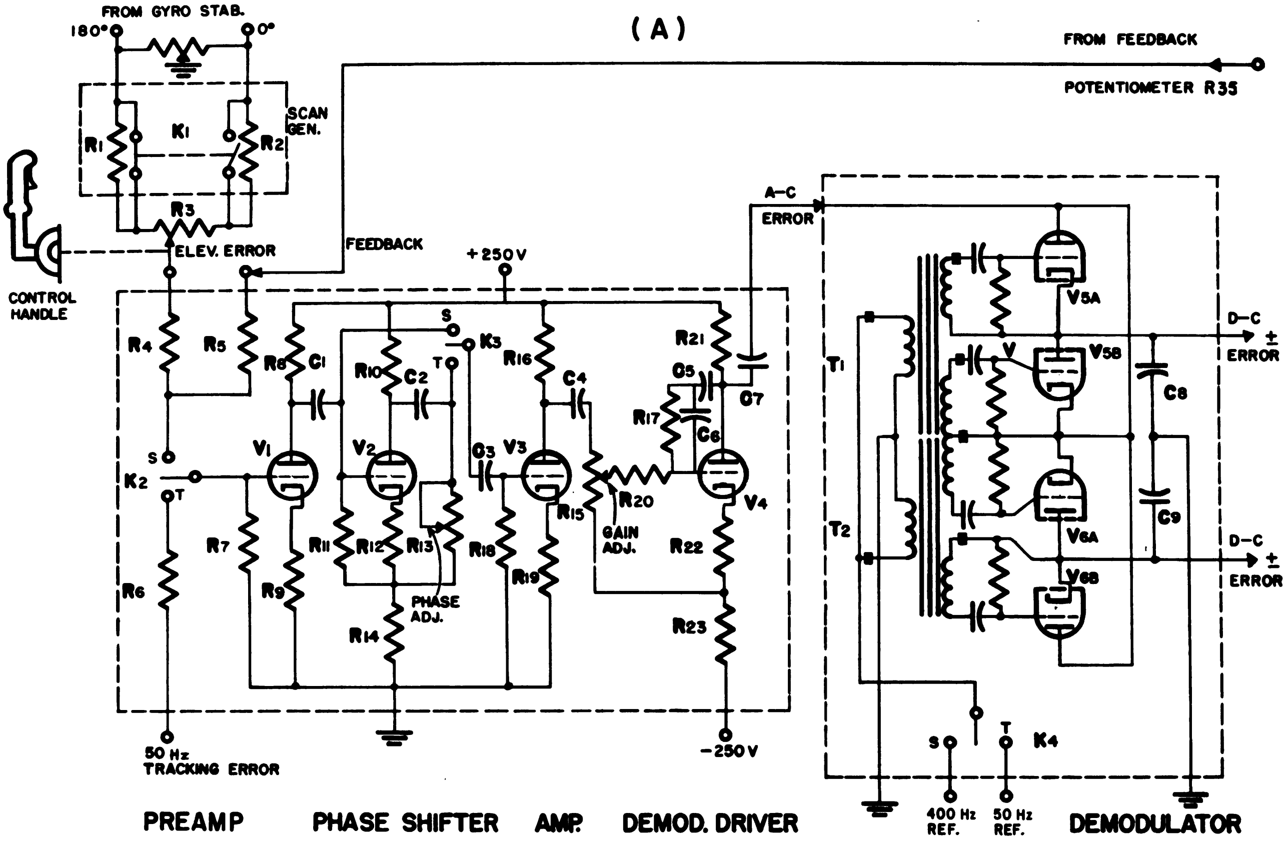


Figure 6-33.—(A) Servosystem schematic diagram. AQ.369

long time constants. The search filter networks pass a 5-Hz signal while sharply attentuating lower frequencies. This action counteracts the high gain of the magnetic amplifiers giving a flatter overall response for the servosystem.

The magnetic amplifier drivers are d-c amplifiers that control the current through the magnetic amplifier's control windings. The d-c error signal is applied directly to the control grids of the drivers. The amplified d-c error signal is applied to the control windings controlling the output of the magnetic amplifier.

The magnetic amplifier provides the final stage of amplification of the error signal prior to the servomotor or output member. The amplifier consists of four amplifier sections: A, B, C, and D. Each amplifier section has three windings on its core—control, bias, and load. Referring to figure 6-33 (B), note that the control and bias windings of sections A and B are connected in series. The bias level is determined by the setting of potentiometer R30, and the control current is determined by the output of magnetic amplifier driver V9.

The C and D sections are connected in a similar manner with the bias level determined by potentiometer R33 and control winding current determined by the output of magnetic amplifier driver V10. It should also be noted that the load winding of each section has a rectifier connected in series with it, allowing current to flow only in one direction. The polarity of the magnetic field resulting from current in each winding is indicated on the schematic by the direction of the arrows.

A synchrogram of waveforms illustrating the operation of the magnetic amplifier is shown in figure 6-35. With a zero error signal applied to the grids of V9 and V10, conduction in all sections of the amplifier is equal. Waveforms showing the amount and time of conduction of each amplifier section under zero error signal conditions are shown in column A of figure 6-35. It should be noted that waveforms (4)

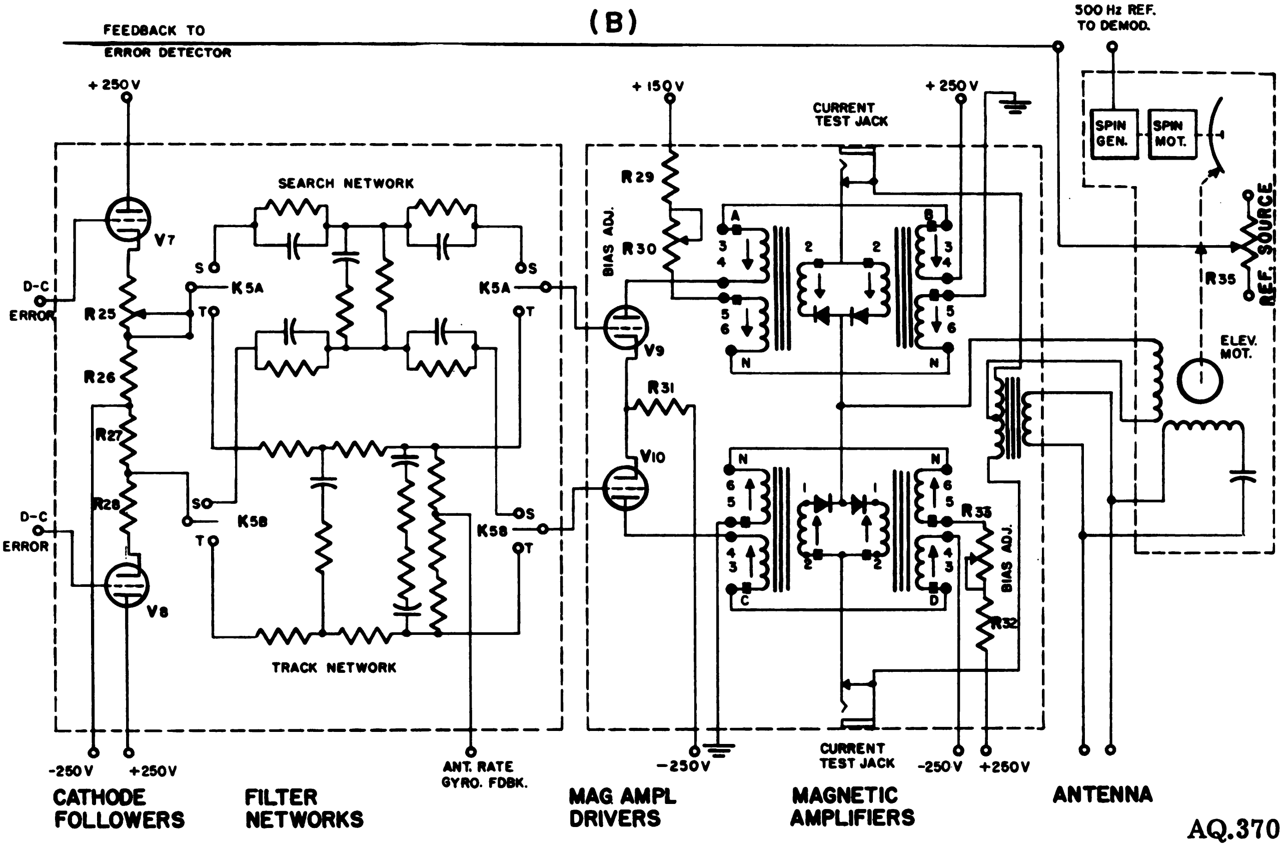


Figure 6-33.—(B) Servosystem schematic diagram.

and (6) are equal in amplitude in column A but 180° out of phase, resulting in zero output to the servomotor.

Column B of figure 6-35 illustrates the operation of the amplifiers with a positive error (an error signal that would cause the antenna elevation angle to be increased) applied to the magnetic amplifier drivers. The positive voltage applied to the grid of V9 increases the degree of core saturation, reducing the impedance of amplifier sections A and B. The negative voltage applied to the grid of V10 decreases the degree of core saturation, increasing the impedance of amplifier sections C and D. Since the output of a magnetic amplifier varies inversely with its impedance, the output of sections A and B is increased in amplitude while the output of sections C and D is reduced in amplitude. Waveform (5) shows the algebraic sum of the two waveforms which is fed to the servomotor.

Column C of figure 6-35 illustrates the operation of the amplifiers with a negative error signal applied. It should be noted that the output amplitudes have been reversed, causing the signal applied to the servomotor to be 180° out of phase with that in column B.

Servomotor

The servomotor is a split phase a-c induction motor whose field windings are excited by voltages that are 90 electrical degrees out of phase. The output of the servoamplifier determines whether the controlled winding is leading or lagging the uncontrolled winding. This phase relationship also determines the direction of rotation of the servomotor.

THEORY OF TRACK OPERATION

The purpose of the antenna servosystem during track operation is to position the antenna based on the video output of the radar system. Again referring to figure 6-33 (A) and (B), note that relay K2 disconnects the error detector and control handle from the servo loop. The 50-Hz envelope of the video output constitutes the error signal and is fed to the servoamplifier.

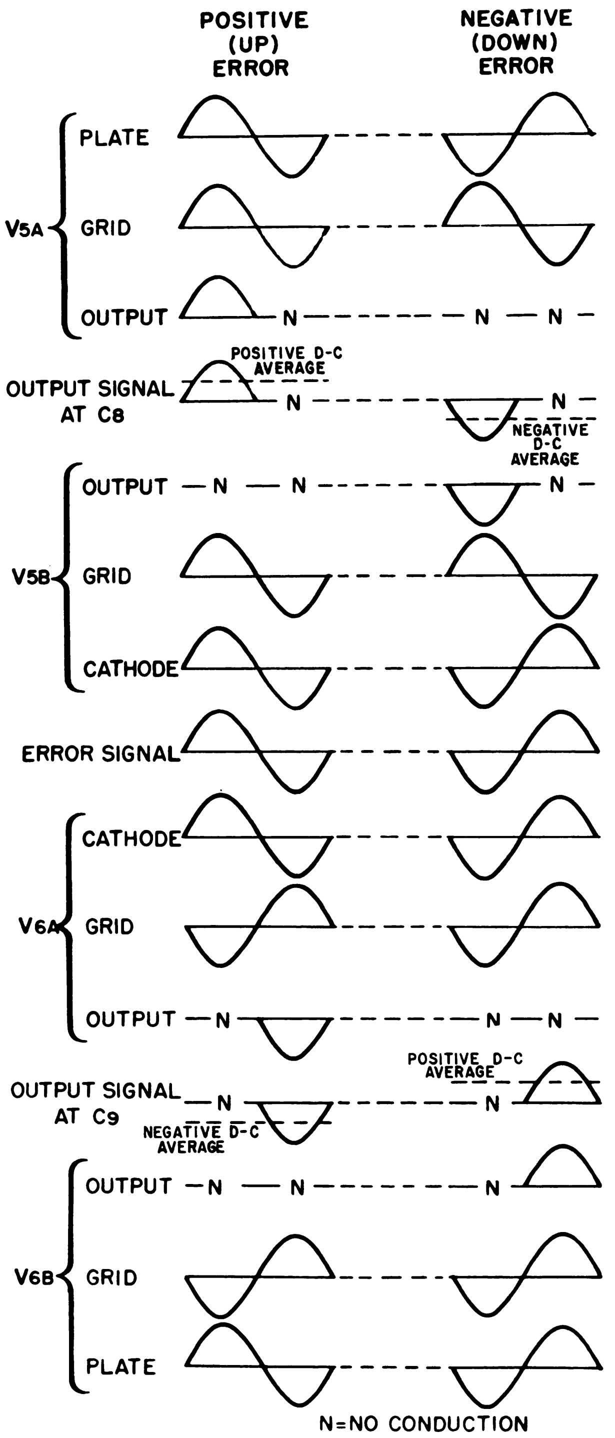


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Figure 6-34.—Synchrogram of demodulator waveforms.

Servoamplifier

The 50-Hz error signal is amplified by the preamplifier and fed to the phase shifter. The phase shifter amplifies the error signal and also provides an adjustment, R13, to compensate for any phase shift of the error signal through the servoamplifier. (See fig. 6-33.) The output of the plate is coupled through C2 to R13 with the other end of R13 connected to the junction of R11 and R12. The plate and cathode voltages are 180° out of phase and regenerative current flows in R12, resulting in regenerative feedback. The shifting of the error signal's phase is accomplished by varying the resistive-reactive ratio of the plate-to-cathode feedback loop. This varies the phase of the regenerative feedback, controlling the phase of the output error signal.

The operation of the amplifier and demodulator driver stages is identical under both modes of operation. However, the demodulator must now employ a 50-Hz reference voltage. Relay K4 is energized by the track/search switch, disconnecting the 400-Hz reference and connecting the 50-Hz reference supplied by the 50-Hz spin generator.

The outputs of the demodulator are fed through the cathode followers to the track section of the search/track networks. The track section is composed of two identical RC bandpass filters, which pass 2-Hz signals and attenuate all other signals. A signal from the elevation rate gyro is also used to control the error signal amplitude during track operation.

Since the magnetic amplifier drivers and magnetic amplifier utilize d-c error signals only, their operation is unchanged when switched to track operation.

Spin Generator

The 50-Hz spin generator is a permanent magnet a-c generator that is driven by the spin motor. Its only function is to furnish a reference voltage for the demodulator during track operation.

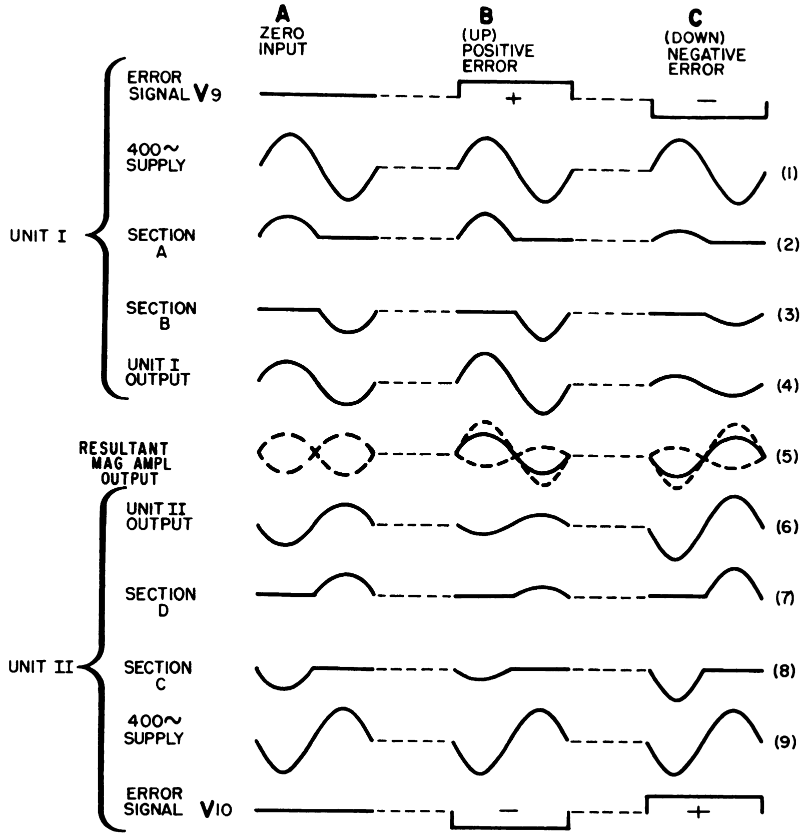

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Figure 6-35.—Magnetic amplifier synchrogram.

MAINTENANCE AND ADJUSTMENTS

The maintenance of the antenna servosystem is normally covered during the odd and even inspections of the entire system. However, it is the purpose of this section of the chapter to discuss maintenance pertinent to a typical antenna servosystem.

Lubrication

The lubrication of the antenna system should follow the procedure set forth in the Maintenance Instruction Manual for the equipment. The lubricants and the time interval between lubrications should also be in accordance with standards established by the maintenance instructions. Instructions are normally issued by the squadron, supplying supplemental maintenance information and establishing schedules to be followed by maintenance personnel.

Alinement

The procedure for alinement of the antenna servosystem is also found in the Maintenance Instruction Manual for each equipment. However, the alinement procedures applicable to the basic antenna servosystem are discussed in this chapter.

The first adjustment to be made is the balance control, R25. (See fig. 6-33.) Its purpose is to insure that there is no output from the servoamplifier when no error signal is applied. Connect a d-c voltmeter between the grid of V9 and the grid of V10. Place a jumper between the grid of V7 and the grid of V8. This shorts out any error signal and allows any imbalance of the cathode followers to be determined. Adjust R25 until there is a zero voltage reading on the voltmeter. Remove the voltmeter from the circuit but do not disconnect the jumper as it is required for the next adjustment.

The bias adjustments in the magnetic amplifiers are made by connecting a milliamp meter in the load winding of each amplifier and adjusting the bias controls, R30 and R33, to the current specified by the Maintenance Instruction Manual. A current jack is normally incorporated in the equipment to facilitate the use of standard milliamp meters. Remove the jumper from the grids of the cathode followers and disconnect the meter.

The gain adjustment is made by inserting a voltage of a specific amplitude and frequency at the input of the preamplifier and measuring the output of the demodulator driver V4, which is the last a-c amplifier stage. The Maintenance Instruction Manual will normally specify the amplitude and frequency of the input signal as well as that of the output stage.

The phase adjustment is made when the equipment is in track operation and locked on a strong target. Disable the antenna azimuth channel by removing the demodulator tubes or at some other location specified by the Maintenance Instruction Manual. With the equipment operating as specified above, manually rotate the antenna in azimuth. Any change in the elevation of the antenna indicates an undesirable phase shift in the amplifier. The phase adjustment must be varied until any movement of the antenna in azimuth causes no change in its elevation.

Adjustment potentiometers normally have locknuts to prevent vibration from affecting their setting. The locknut must be loosened prior to adjusting and care taken when tightening in order not to disturb its setting. The locknut is normally sealed with glyptol to prevent the locknut being loosened due to vibration.

HYDRAULIC SERVOSYSTEM

Another type of antenna servosystem that is in use is a hydraulically driven antenna. This system has the advantages of low response time to a command signal, low weight-to-power ratio, and a high degree of accuracy. Figure 6-36 shows a simplified block diagram of such a system. Only the azimuth channel is shown, as the elevation channel functions similarly.

The antenna drive system converts the electrical energy from the magnetic amplifier into hydraulic pressure which is used to drive the antenna. Antenna position information is mechanically coupled to the induction followup potentiometer which sends a feedback voltage to the magnetic amplifier, nulling out the command signal.

Figure 6-37 shows a diagram of a servo valve and actuator which is used to actuate an antenna. Two such devices are required, one for azimuth and one for elevation.

Drive signals from the magnetic amplifier, acting on the driving coils, produce forces on the flapper at the permanent magnet airgap. Hydraulic fluid, under pressure from the aircraft's hydraulic system, enters the servo valve through fixed orifices (1). After passing through the fixed orifices, the fluid continues through the variable area exit nozzles and then to the low pressure return (2).

Normally, the flapper is positioned so that an equal amount of hydraulic fluid flows through each nozzle; thus the pressures in the right and

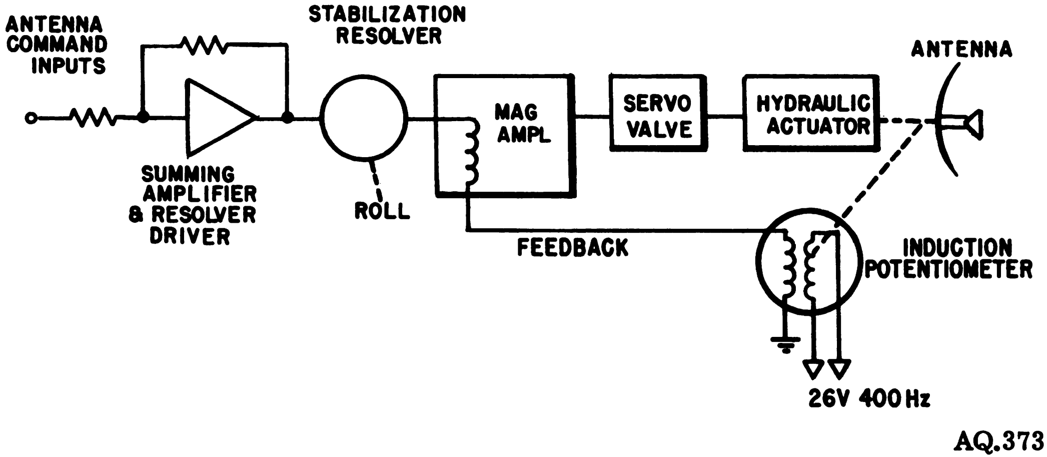

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Figure 6-36.—Antenna positioning circuit.

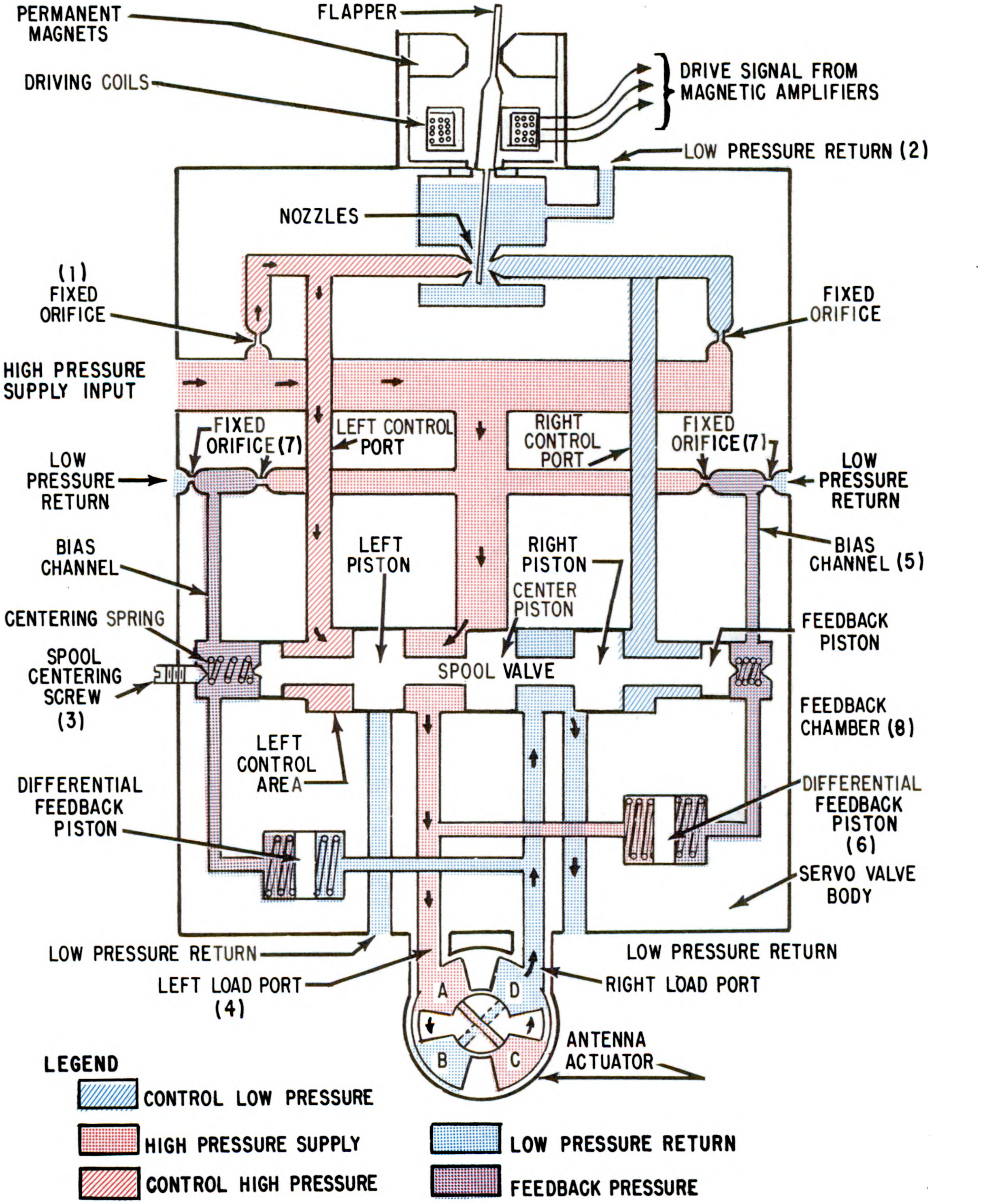

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Figure 6-37.—Servo valve and actuator.

left control ports are equal and the forces on the spool valve are balanced. The spool valve is positioned so that with zero signal conditions, the pistons on the spool valve close off the hydraulic supply and return lines to the antenna actuator. The spool centering screw (3) can be used to adjust the position of the spool valve by balancing the forces developed by the spool valve centering springs.

The flapper moves when a signal passes through the driving coils; the direction and amount of movement depend upon the polarity and magnitude of the drive signal. Movement of the flapper valve to the left increases the pressure in the left control port because the flapper restricts the amount of flow through the left nozzle. Also, flapper movement to the left allows more fluid to flow through the right nozzle, thus reducing pressure in the right control port. The resulting pressure imbalance results in movement of the spool to the right until the counterforce developed by the compression of the spool valve centering spring equals the force developed by the pressure difference across the spool valve. As the spool valve moves to the right, the center piston allows an amount of hydraulic fluid proportional to the drive signal from the magnetic amplifier to flow from the high pressure supply through the left load port (4) into the actuator.

Hydraulic fluid applied to the left load port produces an increase in pressure in chamber A and the pressure increase is transmitted through a hole in the rotor to chamber C. At the same time, chambers B and D are connected to the low pressure return line by the right piston on the spool valve. The pressure difference between the chambers produces a counterclockwise torque on the moving vanes of the rotor. The rotor is connected directly to the antenna gimbal, so that motion of the rotor moves the antenna.

The AQ should be aware of the tendency of servosystems to oscillate. Various types of mechanical and electronic devices (dampers) are used to minimize these tendencies. In hydraulic servosystems oscillation can be damped by the use of hydraulic pressure feedback.

The feedback system is an integral part of the antenna servo valve and consists of a bias channel (5), a feedback channel from each of the antenna actuator drive channels, a differential feedback piston (6), and a feedback piston which is part of the spool valve. Each servo valve has two derivative feedback paths, which together form a push-pull system. Hydraulic fluid from the high pressure supply flows to the return line through two fixed orifices (7), which are designed so that the bias pressure in the chamber between the orifices is approximately equal to one-half the supply pressure. The bias pressure is applied to one side of the differential feedback piston (6), which moves until the restoring force developed by the appropriate centering spring in the piston chamber equals the force developed by the bias pressure.

The other side of the differential feedback piston is connected through the feedback channel to the load port of the opposite channel. The cross-coupling makes the feedback 180° out of phase with the driving signal, providing negative feedback. The steady-state pressures in the two feedback chambers (8) are equal, because in the absence of differential feedback piston motion, the feedback chamber pressures are determined by the supply and return pressures at the fixed orifices. Any change in the input drive signal changes the pressure in the appropriate load port. When coupled through the feedback channels, the pressure change causes the differential feedback pistons to move so that the pressures in the feedback channels and the bias channels tend to be equalized. However, the change in bias pressure (caused by the movement of the differential feedback piston) bleeds off into the low pressure return line at a rate determined by the size of the fixed orifices (7), returning the forces on the feedback pistons to their balanced condition.

While the differential feedback piston is in motion, the pressure it develops within its chamber opposes the motion of the spool valve caused by the input drive signal. The force developed in the feedback chamber is proportional to the rate of change of the drive signal to the torque motor; the greater the rate of change of the drive signal, the greater the instantaneous feedback pressure.

Hydraulic servo valves and actuators are precision devices. The parts are delicately balanced and can easily be damaged by rough treatment and contamination. The torque motor, for instance, can be ruined by tapping it with a screwdriver handle. The components must be handled with care; avoid dropping or jarring, and take care to prevent wrenches and other tools from striking them. When replacing hydraulic components, extreme care must be exercised to prevent contamination of the system. The necessity for cleanliness cannot be overemphasized. The spool valve and the small filters within can be jammed or damaged by dirt. The valve can become prematurely loaded by contamination introduced through careless handling. Even the tinest particle from a person's finger can completely block the servo valve and precision orifices. These orifices are as small as a human hair, and they do not have to be completely blocked to destroy their operation.

CHAPTER 7

DATA SENSING ELEMENTS

In modern naval aircraft, mechanical and electrical devices for sensing changes in direction, attitude, and acceleration are indispensable. Among the systems which depend upon such devices for their operation are the following:

1. Gyrocompass systems.
2. Flight control systems.
3. Radar and gun platform stabilization systems.
4. Antenna rate tracking measurement systems.
5. Inertial navigation systems.

Two devices which are used to sense these changes are the accelerometer and the gyroscope.

ACCELERATION SENSING

The device used to sense accelerations (changes in speed or direction) is called an accelerometer. Its output is usually in the form of a voltage proportional to the acceleration to which it is subjected. Accelerometers are utilized in weapons control systems to detect and to measure acceleration in any desired geometrical plane for such purposes as:

1. Provide information to a computer, whereby it may correct for gravity drop of the projectile when the aircraft is performing maneuvers other than straight and level flight.
2. Provide information to a computer to aid in determining the release point during loft and toss bombing runs.
3. Provide information to the gyroscopes used to maintain stable reference platforms to prevent the gyroscopes from precessing on false gravity inputs.

It should be remembered that the use of accelerometers in weapons control equipments is not limited to the three previously mentioned applications.

THEORY OF OPERATION

Before considering the theory of operation of the accelerometer, Newton's first law of motion should be reviewed. Newton stated in part that every body moving with a constant velocity (hence in a straight line) continues in a straight line until acted upon by an outside force, causing it to change its state of motion. The application of this law provides the basic principle on which the accelerometer operates.

Basically, an accelerometer consists of a mass suspended like a free swinging pendulum within a case. When the case and pendulum are traveling at a constant velocity, the pendulum remains in its center position. However, when the case is accelerated, the pendulum will appear to swing in the direction opposite to that of the accelerating force. It may also be said that the case tries to "outrun" the suspended mass, causing a change in the relationship of the mass and case.

In actual practice, the mass is held in its null or zero position with a calibrated spring or springs. To further dampen oscillations, the case is normally filled with a fluid. Since the deflection of the pendulum is proportional to the accelerating force, the amount of deflection (hence the accelerating force) is measured and transmitted to other units for use in the solution of the armament control problem.

POTENTIOMETER TYPE ACCELEROMETER

The potentiometer type accelerometer (fig. 7-1) is used in present day aircraft in the solution of loft and over-the-shoulder bombing problems. It measures the G's pulled by the aircraft during the maneuver and aids immeasurably in determining the point of release of weapons. It is also used to aid in solving air-to-air gunnery and missile problems.

E-TRANSFORMER TYPE ACCELEROMETER

The E-transformer type accelerometer (fig. 7-2) is used to detect excessive horizontal acceleration that could cause false gravity inputs to the stabilizing gyroscopes. The normal installation utilizes two accelerometers. One is mounted parallel to and along the pitch axis of

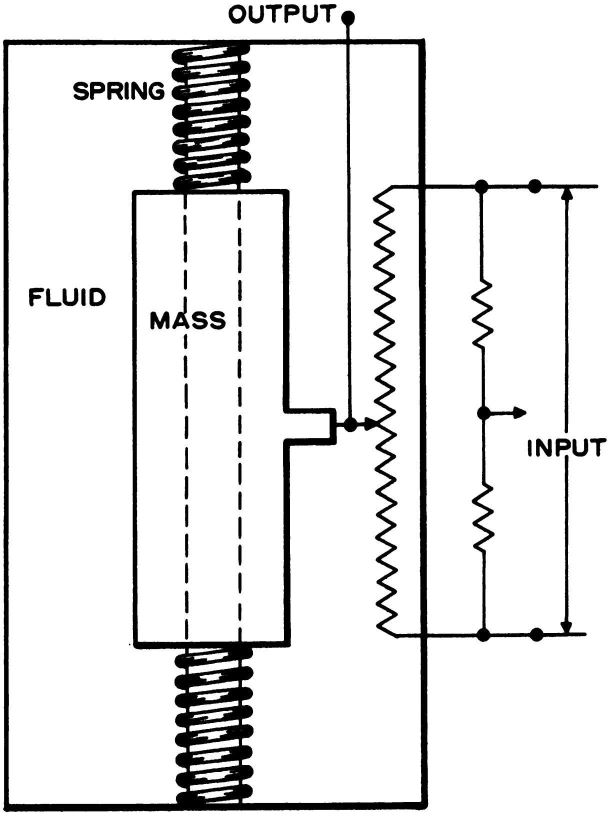

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Figure 7-1.—Typical potentiometer type accelerometer.

the platform to detect excessive accelerations along that axis. The other is mounted parallel to and along the roll axis of the stabilized platform for the purpose of detecting excessive accelerations along the roll axis.

FORCE BALANCE ACCELEROMETER

An accelerometer commonly used with inertial navigation systems is the force balance accelerometer. A schematic representation of this type is shown in figure 7-3. The pickoff coil, the mass, and the torquer coils are all situated on a common movable shaft, which has the ability to make a partial rotation about its pivot point axis.

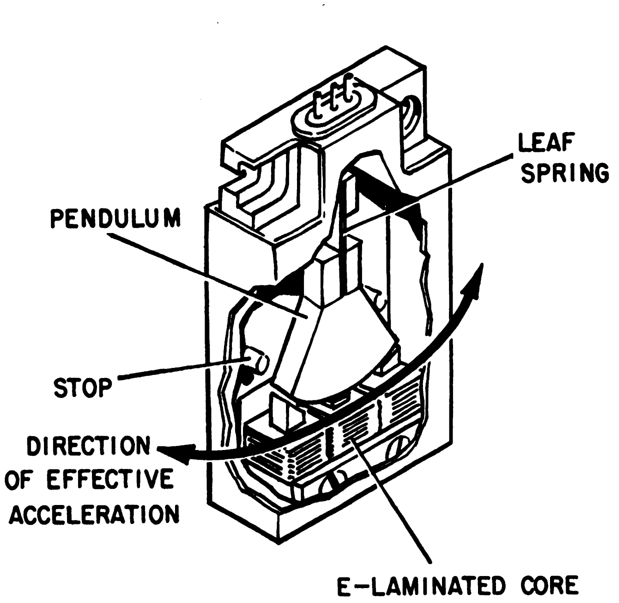

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Figure 7-2.—E-transformer type accelerometer.

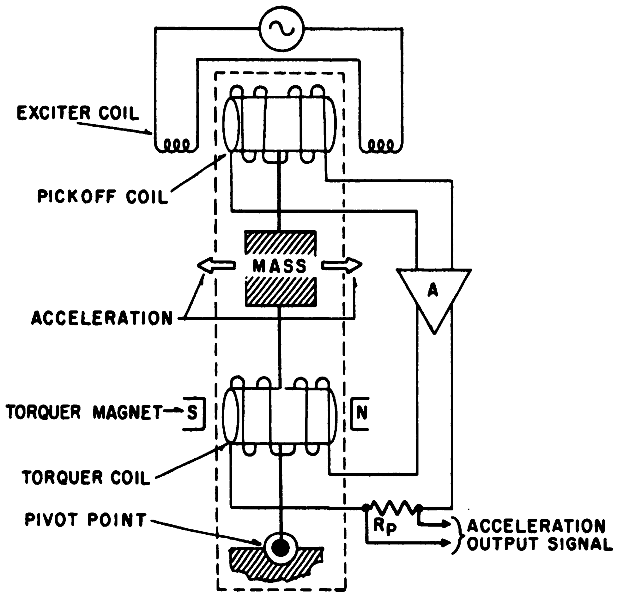

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Figure 7-3.—Force balance accelerometer.

PULSE COUNTING ACCELEROMETER

Though the output of a force balance accelerometer is an analog current proportional to acceleration, there is need for accelerometer output signals to be in digital form. Pulse counting accelerometers satisfy this need, since their pulse output can be supplied directly to

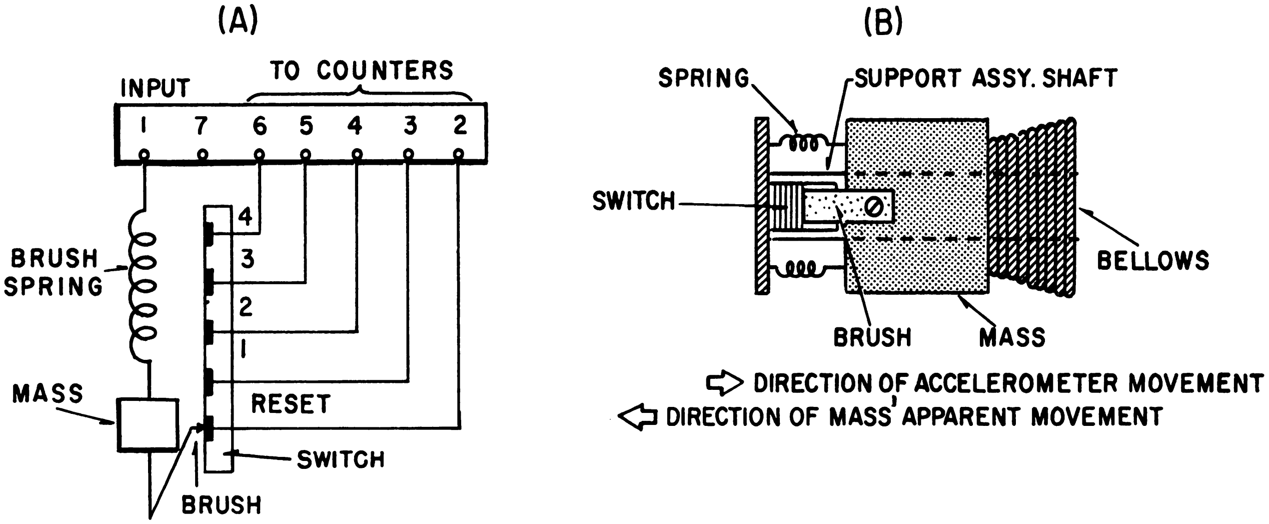

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Figure 7-4.—Pulse counting accelerometer. (A) Schematic diagram; (B) cutaway.

computers. A schematic of a pulse counting accelerometer circuit can be seen in figure 7-4 (A), while the cutaway view is shown in figure 7-4 (B).

Normally, a minimum of maintenance is performed on accelerometers by the Aviation Fire Control Technician. Maintenance usually consists of performing operating checks as prescribed by the Maintenance Instructions Manual for the applicable equipment. Defective units should be replaced and forwarded to an overhaul shop where repair can be performed by qualified personnel using proper equipment.

ATTITUDE AND DIRECTION SENSING

The gyroscope is the world's oldest mechanism, since the earth itself is a gyroscope. The earth's daily rotation about its axis has provided the stabilizing effect that has kept the North Pole pointed within 1° of Polaris (the North Star) probably since the beginning of time; but has definitely done so since the recorded knowledge of man. This stability of the earth's spin axis illustrates one of the basic properties of the gyroscope, and this same persistence in manmade gyros is the basis of many modern instruments.

The first manmade gyroscope was built by a French physicist named Foucault, which he used in his demonstration to show the earth's rotation. He also named the apparatus. The word gyroscope was derived from the Greek words "gyros," meaning revolution, and "skopein," meaning to view. These two words, when combined, mean "to view the revolution." His choice of this name was quite appropriate, since his invention made the rotation of the earth visible.

TERMINOLOGY AND CHARACTERISTICS

Before considering the various types of gyros and their characteristics, first consider some of the terms associated with the principal parts of a typical basic gyro, as shown in figure 7-5. Basically, a gyroscope is a spinning mass supported so that its spin axis has unlimited rotational freedom. The rotating mass is called the rotor or wheel, and is in itself the gyroscope or the gyroscopic element.

Various kinds of rotor supporting structures have been devised to provide the gyroscopic element unlimited rotational freedom. The frames or rings which support a gyroscope are called gimbals, and the use of these gimbals to achieve rotational freedom of the gyroscope is called gimbaling.

The first or outer gimbal is free to rotate about an axis determined by the outer bearings

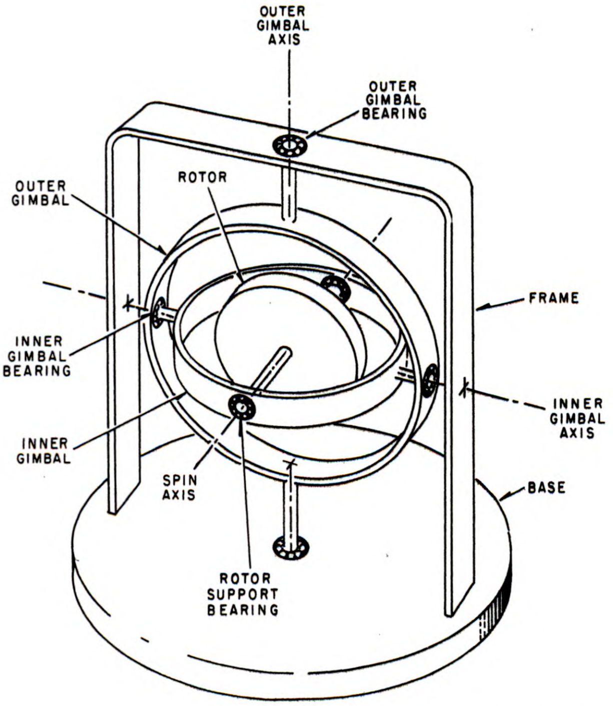

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Figure 7-5.—Principal parts of a gyro.

fixed in the base. A second set of bearings, called inner gimbal bearings, is mounted in the outer gimbal perpendicular to the axis of the first set. These support a second or inner gimbal. Theoretically, the inner gimbal and all of the components fixed to it have unlimited rotational freedom with respect to the base.

The gyroscopic element or rotor is suspended in the inner gimbal, and its spin axis is perpendicular to the inner gimbal axis. Generally, when the gyro is operating, all three axes are more or less perpendicular to each other. However, the outer gimbal and the spin axes may have a relationship other than perpendicular.

Degrees of Freedom

A gyro can have different degrees of freedom, depending on the number of gimbals in which it is supported, and the manner in which the gimbals are arranged. The term "degrees of freedom" as used in this chapter, must not be confused with an angular value as degrees of a circle. The term as used with gyros is an indication of the number of directions in which the rotor is free to move.

A gyro enclosed in only one gimbal (fig. 7-6) has only one degree of freedom. This degree of freedom is at right angles to the axis of spin. Assume that this gyro is mounted in an aircraft with its spin axis parallel to the axis of travel. The rotor is spinning and it is free to move from left to right (it has one degree of freedom). This gyro has no other freedom of movement. Therefore, if the aircraft should nose up or down, the plane containing the gyro spin axis would move exactly the same as the aircraft. However, if the aircraft should turn right or left, the gyro would not change its attitude, since it has a degree of freedom in these directions.

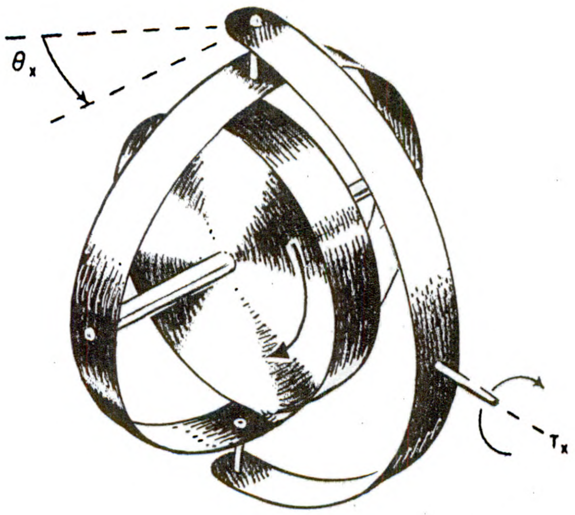

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Figure 7-6.—Single degree-of-freedom gyro.

A gyro mounted in two gimbals normally has two degrees of freedom. Such a gyro can assume and maintain any attitude in space. Consider a rubber ball in a bucket of water. Even though the ball is supported by the water, it is not restricted as to attitude by the water, and can lie with its spin axis in any direction. Such is the case with a two-degree of freedom gyro (often called a free gyro). (The gyro in figure 7-5 is a two-degree-of-freedom gyro.)

This means that if the base surface turns around the outer gimbal axis, or around the inner gimbal axis, the gyro spin axis stays put.

In other words, the gimbaling system isolates the rotor from the base rotation.

Rigidity

As can readily be seen, one of the basic properties of the gyroscope is its reluctance to change position; it wants to remain where it is in space. This property, known as rigidity, is the characteristic of any spinning body which causes it to oppose any attempt to tilt it away from the axis in which it is spinning. A wheel spinning on its axis is in effect a gyro, and offers opposition to any attempt to tilt it from its assumed position in space. The gyro rotor is not rigid as one would think of a tree; it can be moved in several ways. In fact it can be moved freely from one place to another so long as it is not tilted. When a rotor is spinning on its axis and an attempt is made to tilt it, it opposes this effort. The amount of opposition offered by the spinning gyro depends on the weight and shape of the spinning body and the speed at which it is spinning.

To understand the effect of weight distribution in a gyro rotor, take two rotors of the same weight, the diameter of one less than that of the other, as shown in figure 7-7. When both of these rotors spin at the same speed, the rotor with the greater diameter is much more rigid than the one with the smaller diameter. Next, it is found that both rotors can be made equally rigid by causing the rotor with the smaller diameter to spin faster than the larger one. Thus, it is evident that rigidity is dependent upon both speed and distribution of weight.

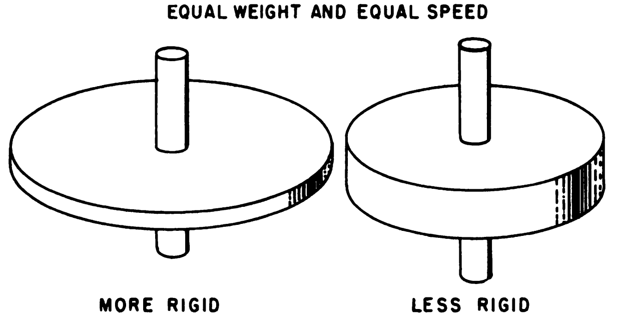

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Figure 7-7.—Gyro rotors.

Now it can be concluded that a gyro tends to oppose any tilting force, and that the extent of this opposition depends upon the weight, distribution of the weight, and the speed of rotation of the rotor. If a gyro was designed for maximum rigidity, it would be made as heavy as possible, with as much of the weight placed the maximum distance from the center of rotation, and it would be rotated at the maximum possible speed.

Precession

The second useful property of the gyroscope is a peculiar motion called precession. If a force is applied to the axis of a spinning gyroscope, the axis rotates in a direction 90° from (at right angles to) the direction in which the force is applied.

In a gyroscope, the reaction of precession occurs simultaneously with the phenomenon of rigidity. These two reactions are very closely related. A gyro does not have rigidity if it does not precess; and conversely, a precessing gyro always offers a degree of rigidity.

The tilting force that causes a gyro to precess is called torque since it acts at a distance from the center of gravity of the rotor. A man riding a bicycle who leans to the right or to the left applies a torque to both the front and rear wheels. When a torque is applied to a gyro, instead of going along with the tilting force, the gyro takes matters into its own hands, and tilts itself in a direction that is at right angles to the direction of applied torque, or the precession of a gyro will be in the direction of rotation and 90° ahead.

Precession is always a reaction to an attempt at tilting a spinning rotor; that is, rotating the spin axis, or in other words, imparting rotational motion to the gyro. One cannot precess a gyro—one can only give a gyro a torque that will cause the gyro to precess itself.

In order to understand gyros, it is absolutely necessary to understand what direction a gyro will precess in response to an applied torque. This characteristic of a gyro follows a very simple rule: The gyro always tries to aline itself, by precession, in such a way that its direction of spin is the same as the direction of the applied torque.

If a person is riding a bicycle and leans to the right, he is leaning in a clockwise direction and the front wheel turns itself so that it is spinning in the same clockwise direction. (A bicycle is not a perfect example of precession, because its reaction to the leaning of the rider is partly due to precession and partly to the castered arrangement of the wheels; but it is useful as an example, because it is familiar to everyone and is easy to remember.)

REAL PRECESSION.—Real gyroscopic precession is that property of a gyro which causes the rotor to be displaced, not in line with an applied force, but 90° away from the applied force, and in the direction of rotor rotation. When a downward force is applied at point A (fig. 7-8) the force is transferred through pivot B as a downward force at C. This force travels 90° in the direction of rotation and causes downward movement at D with subsequent movement (precession) at E.

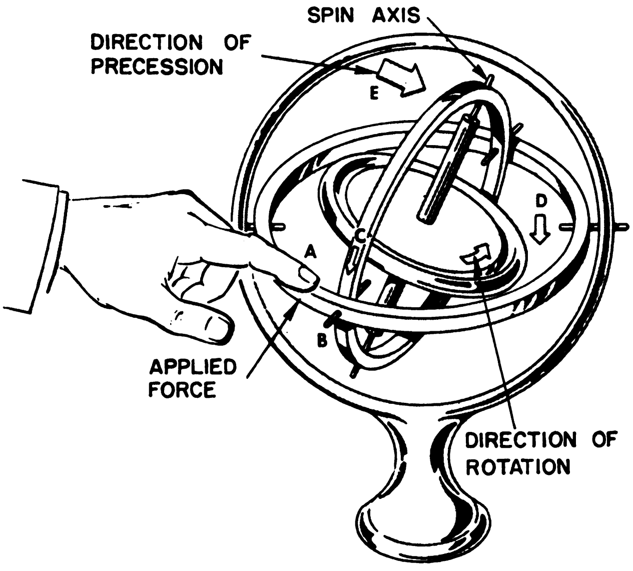

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Figure 7-8.—Gyroscope precession.

If a force were applied to the rotor at its center of gravity, it would not act to tip the gyro spin axis from its established position. Therefore, no precession would take place. Thus a spinning gyroscope can be moved in any direction as easily as a gyro at rest, provided the spin axis remains parallel to its original position in space. Movement of this kind is called translational movement.

The gyro, therefore, provides stability only against tipping its spin axis. Thus a spinning gyroscope cannot provide stabilization in planes perpendicular to its spin axis. For complete stabilization in aircraft, two gyroscopes, are required. For this reason, both a vertical gyro and a horizontal gyro are needed to give complete stabilization and to set up the necessary reference lines from which deviation can be measured in roll, pitch, and yaw axes.

APPARENT PRECESSION.—Because rigidity fixes the spin axis of a gyro in space, the axis points in a fixed direction. However, the earth, which is rotating, turns under the gyro. Thus, the axis of the gyro appears to tilt. For example, imagine a gyroscope at the Equator with the spin axis horizontal to the earth and pointed in an east-west direction, as shown in figure 7-9. The earth turns in the direction of the arrow (clockwise) with an angular velocity of 1 revolution every 24 hours. To an observer out in space, the gyro spin axis would appear to maintain its position, pointing east. But to an observer on the earth, the spin axis appears to gradually tilt or drift. At the end of 3 hours, the spin axis has tilted 45°, and after 6 hours the spin axis has tilted 90° to a vertical position. The apparent precession is indicated in figure 7-10. At the end of 12 hours, the spin axis is again horizontal, but points west; and at the end of 24 hours, it is back in its original position, pointing east. The X on each gyro in figure 7-10 indicates the direction the spin axis is pointing.

This phenomenon creates the illusion that the gyro has turned over, end for end, and that a complete revolution is made every 24 hours. Actually, however, the gyro has maintained its position in space, and the earth has moved around it. This movement of the earth in relation to the gyro is called apparent gyroscopic precession.

Apparent precession of a gyro makes it unfit for use as a reference over an extended period of time unless some sort of compensating or erecting mechanism is used to keep the gyro in a fixed position relative to the earth's surface. Over a relatively short period of time, however, the gyro can be used to establish a satisfactory reference without the need for an erecting mechanism.

Gyro Drift

The gyro spin axis does not always point in the direction it theoretically should. This error in the gyro is produced by random inaccuracies in the system. The resulting change in position

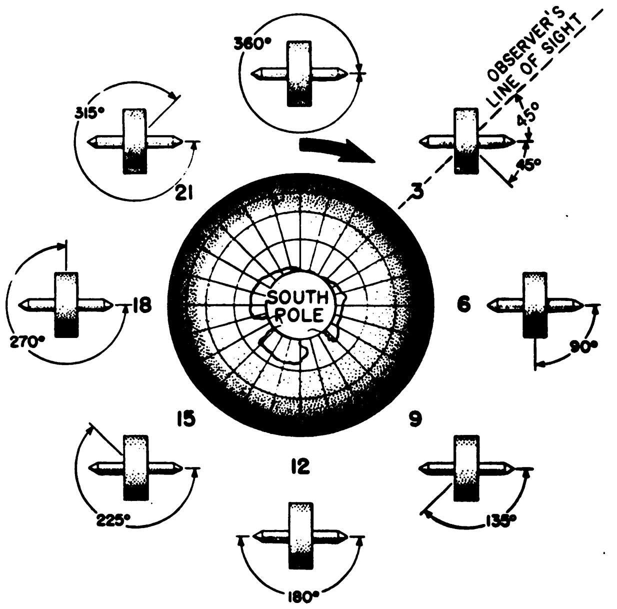

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Figure 7-9.—Apparent gyro precession viewed from outer space.

of the spin axis is called drift. There are three general sources of drift in a gyroscope:

1. Imbalance. A gyroscope often becomes dynamically unbalanced when operating at a speed or temperature other than that for which it was designed. Some imbalance exists in any gyro since manufacturing processes do not give perfect symmetry.

2. Bearing friction. Friction in the bearings of the gimbals results in lost energy and incorrect gimbal position. Friction in the spin axis bearing causes drift only if the friction is not symmetrical; an even amount of friction all around in a bearing results only in a change in the rate of rotation.

3. Inertia of the gimbals. Energy is lost whenever a gimbal rotates because of the inertia of the gimbal. The greater the mass of the gimbal, the greater the drift from this source.

Complete elimination of drift in gyroscopes appears to be impossible. However, great strides have been made in recent years toward reducing the amount. In the process of reducing errors to an acceptable margin, the gyros of today have become very delicate instruments and cannot withstand rough handling. In fact the bearing surfaces of some of the gyros presently in use are so fine they deteriorate while in storage.

GYRO OPERATION

Three vectors must be considered when discussing the operation of a gyro. A vector represents a physical quantity that has both magnitude and direction. For example, velocity is a vector quantity; it has magnitude (knots or miles per hour) and direction (such as north).

The three basic vector quantities are:

1. Spin vector, the angular velocity of the gyro rotor.
2. Torque vector, the rotary motion applied to change the direction of the rotor axis.
3. Precession vector, the resulting angular velocity of the rotor axis when torque is applied.

All three motions are rotary (angular) and can be represented by vectors which point in such a direction that when looking in the direction of the vector the rotary motion is clockwise.

Right Hand Rule

A convenient rule for determining the direction of precession is by the use of the fingers of the right hand. This method is not new since a similar means is used to demonstrate the motion of a conductor in a magnetic field, as described in Basic Electricity.

The three vectors previously mentioned may be represented by arranging the thumb, index finger, and middle finger of the right hand mutually perpendicular as shown in figure 7-11. The thumb points in the direction of the spin vector, the middle finger points in the direction of the precession vector, and the index finger points in the direction of the torque vector. These vectors can be considered as the axes about which angular motion takes place. All rotary motions are clockwise as indicated in the figure when viewing in the direction that the fingers and thumb are pointing.

The hand rule is useful for analyzing any gyroscope motion problem. If the direction of any two of the three vectors are known, the direction of the third vector can be found and the motion around this vector may be determined.

Still another use of the hand rule is in determining the direction of the spin vector (fig. 7-12). By curving the fingers of the right hand around the gyro in the direction the rotor is turning, the thumb will then point in the direction

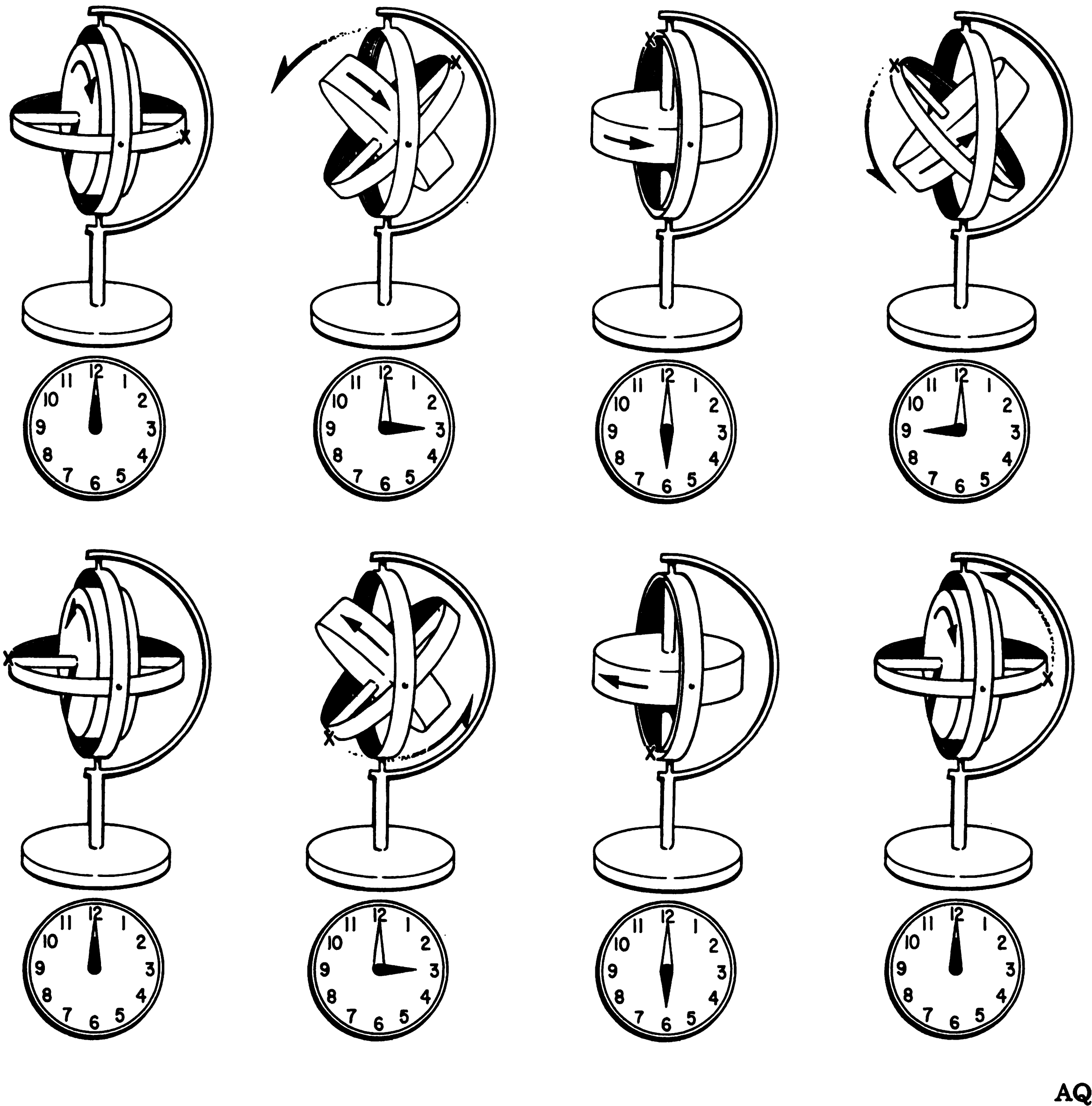

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Figure 7-10.—Apparent gyro precession as viewed by an observer on earth.

of the spin vector. Also the direction of the torque vector may be found by wrapping the fingers in the direction of the applied torque (the direction the gyro would rotate if the rotor were not spinning); the thumb points in the direction of the torque vector.

Orientation

Gyroscopic elements are oriented with the various axes of the aircraft. The manner in which this is accomplished depends, to a certain extent, on the equipment and the functions the gyros are expected to perform. Figure 7-13 illustrates the three axes of an aircraft and their relationship to the gyro spin axis. With the gyro mounted as shown, the amount of pitch and/or roll of the aircraft can easily be measured, as the gyro will maintain a stable reference as the aircraft maneuvers.

Gyros may be oriented with any of the aircraft's axes and may also be used in combinations

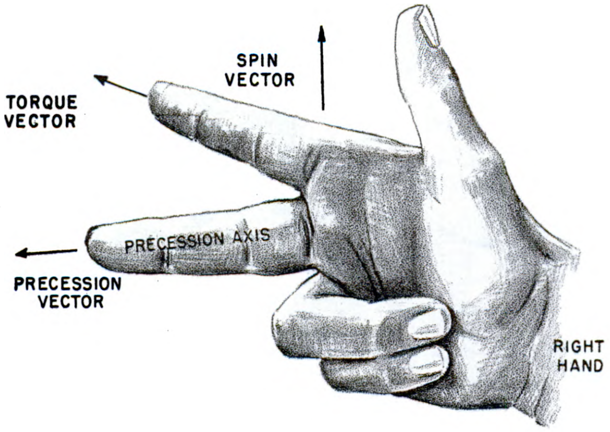

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Figure 7-11.—Using right hand to illustrate relationships associated with the law of gyroscopic precession.

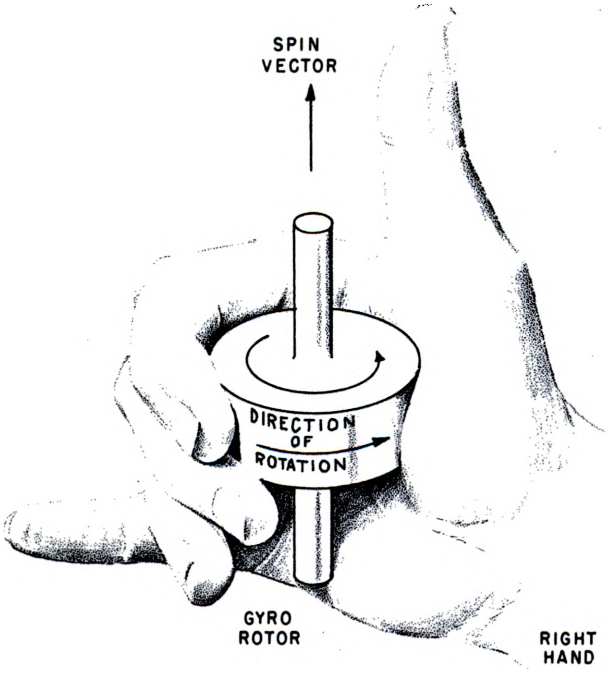

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Figure 7-12.—Determining spin vector direction.

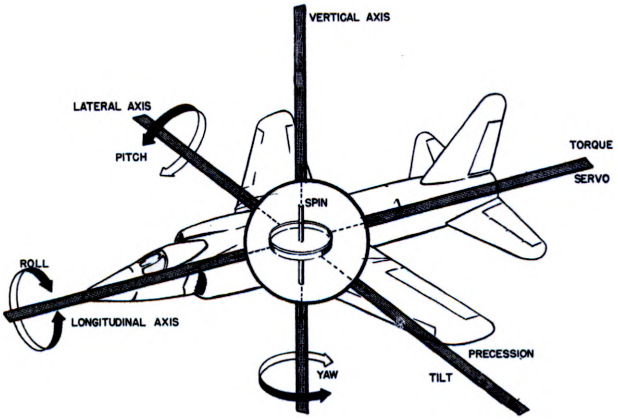

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Figure 7-13.—Relationship of gyro axes to the aircraft axes.

of two or more for determining rates and amounts of movement about any or all of the aircraft's axes. Therefore, to fully understand some of the weapons control equipment, it is necessary to understand the orientation of the gyro elements in the equipments and their relationship to the axes of the aircraft.

Pickoff Devices

To utilize a gyro as a detecting device for solving aircraft armament control problems, it is necessary to adapt it with some type of pickoff device. This is necessary so that the desired information can be determined and transmitted to the desired unit. Some of the devices used for this purpose are E-transformers, potentiometers, and synchros. These devices were discussed in chapter 6 of this manual.

Gimbal Lock

Gyros may become damaged in the aircraft as a result of the phenomenon known as gimbal lock, unless some method is used to prevent it. As was previously mentioned, gyros are usually mounted so that the spin axis, inner gimbal axis, and outer gimbal axis are mutually perpendicular during normal operation. This is the condition of the free gyro in an aircraft during straight and level flight.

When the aircraft maneuvers, however, the condition as described no longer exists. In order for the gyro rotor to maintain its position in space as the aircraft rolls, climbs, and dives, the gimbals must change their position relative to each other. The maneuvers performed by transport type aircraft present no problem. But in a fighter or attack type aircraft the maneuvers are often quite severe and gimbal lock could be encountered.

Gimbal lock occurs when the spin axis and the outer gimbal axis coincide. This condition exists whenever the aircraft passes through the 90° climb or dive position. When gimbal lock occurs in a free gyro, it can no longer maintain its two degrees of freedom. Because the gimbals are locked, if the aircraft sustains a rolling motion, the gimbals are unable to compensate for it and the gyro tumbles; that is, the gyro spins end over end, and the reference is lost.

If a perfect loop were executed, that is with no yaw or roll, gimbal lock would be no problem. Such a loop is virtually impossible because of the aerodynamic characteristics of the airframe. Therefore, gimbal stop pins are generally used to prevent the spin axis from becoming alined with the outer gimbal axis. When stop pins are used, the gyro simply precesses 180° as the aircraft goes through the 90° climb or dive position. Gimbal stop pins usually limit gimbal movement to angles of about 85° from the horizontal. This means that the gyro reference is lost while the aircraft is in the 85° to 95° position, but this is better than losing it entirely.

APPLICATIONS

As previously mentioned, gyroscopic instruments make use of the two basic properties of the gyro: rigidity in space and precession. Rigidity is used to establish a reference in space which is unaffected by movement of the supporting body; and precession is employed to control the effects of the earth's rotation, bearing friction and imbalance, thus maintaining the reference in the required position.

For blind flying, in clouds, for example, an artificial horizon is essential. A free gyroscope provides the reference for the operation of the artificial horizon. In this case the spin axis is made vertical before takeoff or during contact flying and is called a vertical gyro. The gyro then maintains the reference for a period of time depending on its precision of construction and length of time it is required to provide the reference.

A free gyro may also be used to provide an azimuth reference. The gyro is initially set with its spin axis horizontal and in some prescribed compass direction, such as north. When used in this configuration it is called a directional gyro. The gyro will maintain the preset direction reference for reasonable periods of time regardless of the attitudes of the aircraft.

A system called a stable platform usually requires the use of both a vertical and directional gyro in combination. Pickoffs on a stable platform measure deviation of the vehicle about three quadrature (mutually perpendicular) axes from a space stabilized coordinate system. On an aircraft these axes are called pitch, roll, and yaw. Auxiliary motors controlled by the sensory signals, are used to move the platform about the three axes to keep the pickoff at or near zero.

Rate Gyro

A rate gyro may be defined as a device for detecting the angular rate of change of position of an object. In weapons control equipment, one major concern is the angular rate of change of a target aircraft. However, this rate of change of the target may be determined by measuring the angular rate of change of an antenna locked on the target. Target angular rate information may also be determined by measuring the angular rate of change of the attacking aircraft while tracking its target.

There are two basic types of rate gyros used in aircraft weapons control equipment. One type senses a rate of change in one geometric plane while the other type senses a rate of change in two planes simultaneously. The latter type is capable of not only measuring rate of change in two geometric planes, but when supplied with range, ballistic, and other necessary information, is capable of determining the necessary lead angle required to hit the target. For the purpose of discussion, these gyros are referred to as one-plane and two-plane rate types.

ONE-PLANE RATE GYRO.—The one-plane rate gyro is used quite extensively in aircraft weapons control equipment. This type is often used in pairs, one for detecting rate of change in elevation and one for detecting rate of change in azimuth. The purpose of this type gyro is to produce an electrical output signal that is proportional to the angular rate of gyro motion about the precession axis. It should be remembered that the rate of motion about the processional axis is proportional to the force applied about the torque axis.

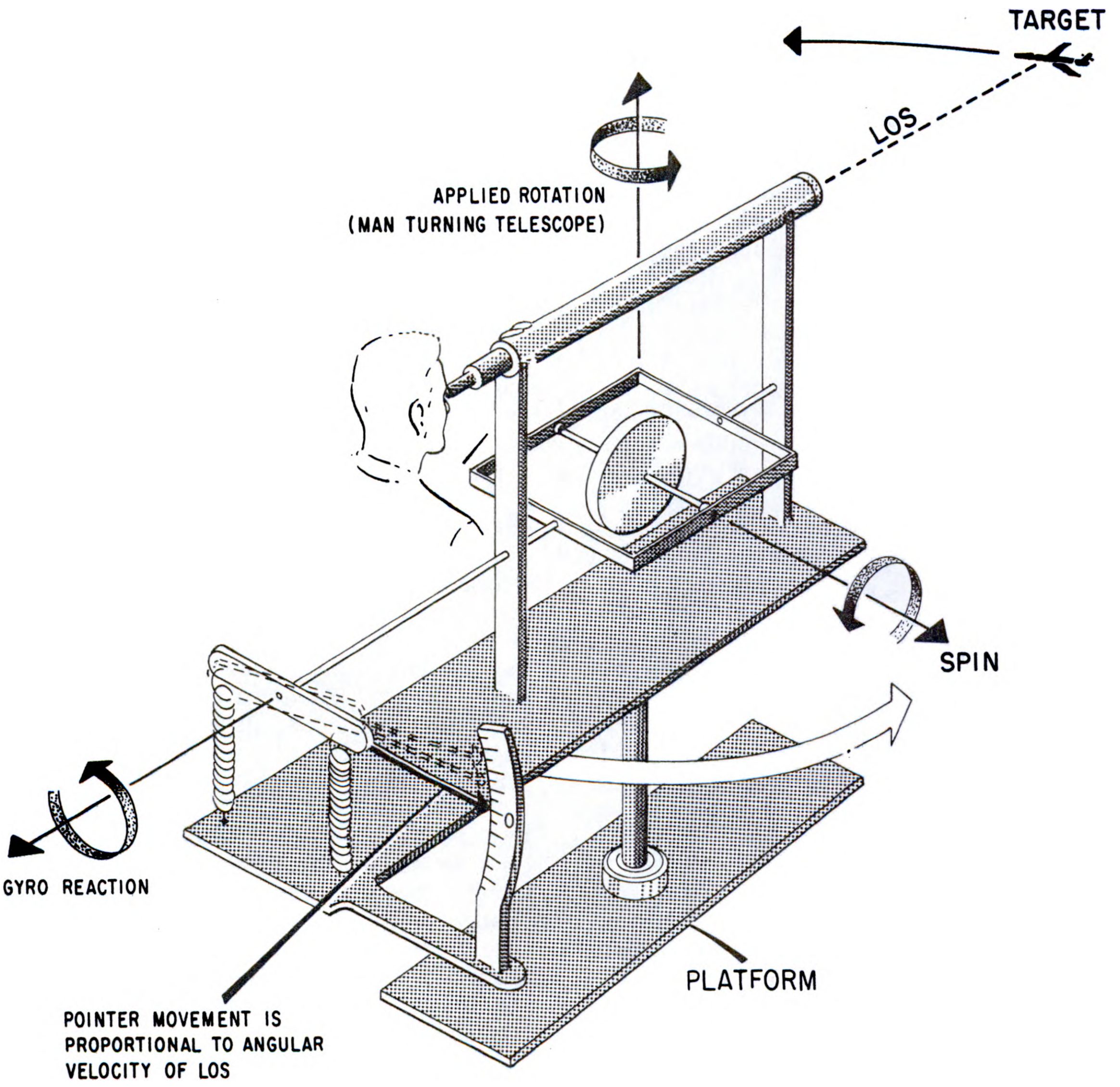

Figure 7-14.—A simplified rate gyro.

A simplified rate gyro is illustrated in figure 7-14. In this case the platform represents the aircraft and the telescope is the radar antenna assembly. As the telescope follows the target, the gyro attempts to aline its spin axis with the axis of the applied rotation. This causes compression and stretching of the calibrated springs and displacement of the pointer. The amount of displacement is in direct proportion to the rate of change in the line of sight (LOS). Thus, this gyro is a rate gyro.

Stabilizing Gyros

A basic free gyro may be used as a stabilizing gyro by modifying the mounting and placing certain limitations on its movement. Unlike the rate gyro discussed previously, the stabilizing gyro is used to establish a fixed reference from which it is possible to measure amounts of movement or displacement. Stabilizing gyros may be used to establish either horizontal or vertical references, and may be used in groups of two or more to establish geometric planes of reference. A typical application of a stabilizing gyro may be found in a weapons control system where it is used to stabilize the radar antenna and measure the amount of roll of the aircraft for use in missile guidance.

In addition to the basic components of a free gyro, a stabilizing gyro has provisions for detecting any deviation from the stabilized reference and transmitting this information to the equipment as required. It normally has some means of erection or alining its spin axis with a predetermined reference. A stabilizing gyro may also include a means of caging; that is, restricting or locking its gimbals.

GYRO MAINTENANCE

The maintenance of gyros is usually restricted to overhaul activities. Some gyros, such as rate gyros, may be sealed and any malfunctions are corrected by replacement.

The gyros used in stable platforms are usually also replaced rather than repaired when malfunctions occur. However, this does not preclude the maintenance, adjustment, and repair of associated parts such as erection devices, synchros, and torque motors, and replacement of devices such as accelerometers and E-transformers normally found in such a stable platform. The electronic circuits found with the gyro may also be repaired. In all cases, the Maintenance Instructions Manual specifies the extent of repairs that may be attempted at a specific level of maintenance. Pitch, roll, and balance adjustments are covered in chapter 6 of this manual under antenna servo systems.

CHAPTER 8

WEAPON CONTROL FUNDAMENTALS

Before a reasonable understanding of weapon control may be obtained, and also to help make the job of the AQ more meaningful, a knowledge of what happens to a projectile on its way to the target after it has been fired or launched is necessary. This chapter is intended to define some of the terms and to describe some of the fundamental problems encountered in aircraft weapons systems. Actually there is only one problem; however, there are many variations of this problem.

PRIMARY PROBLEM

The primary problem of aircraft weapons systems is to accurately determine the correct position and attitude in which to place the aircraft in order to be reasonably sure of making a hit on the target. The problem presents itself in varying degrees of difficulty, depending on the type of weapon used, the type of attack, and whether the target is airborne or on the surface. In almost all cases this requires the generation of what is known as lead angle.

Lead angle can be in either elevation or azimuth, or a combination of both. For example, a duck hunter knows that he must aim his weapon ahead of and above a fast moving bird if he expects to hit the bird. In so doing he is establishing a lead angle that is a combination of elevation lead angle (to compensate for the gravity drop of the shot) and azimuth lead angle (to compensate for the distance the bird travels while the shot travels from the weapon to the bird). Lead angle (fig. 8-1) is a term used to describe the angle which lies between a straight line extending from the weapon to the target and a line projected from the centerline of the weapon.

No matter how difficult or how simple the problem may be, there are two terms that always present themselves in the solution of the problem. One is ballistics, the other is trajectory.

BALLISTICS

Ballistics is a term which refers to the science of the motion of projectiles. It is a study of all the various forces, both controllable and uncontrollable, which govern the movements of projectiles.

The study of ballistics is normally divided into two branches—interior and exterior. The study of interior ballistics is primarily concerned with the movement of projectiles inside the gun barrel or bore. The study of exterior ballistics is concerned with the motion of the projectile after it leaves the bore of the gun or the launcher, and is free in the air.

Interior ballistics is covered by a great number of highly complicated technical subjects which are of little concern to the AQ. However, to gain an insight into how some of the interior ballistic factors affect exterior ballistics, the subject is discussed briefly in the following paragraphs.

The factor having the most effect on interior ballistics is probably the propellant. Broadly speaking, there are two classifications of explosives. They are the high explosives as used in bombs and which burn at an extremely rapid rate (detonate), and the slower (controlled) burning explosives. These slow burning smokeless powders (propellants) burn smoothly and progressively, giving lower pressure in the chamber of a gun but maintaining the pressure for a longer period of time. Thus the projectile is literally pushed into its trajectory.

In rockets and missiles, controlled burning is also utilized and the projectile accelerates until its fuel is consumed. This is usually referred to as burn time.

Another item of interior ballistics of concern to the AQ is the fact that all aircraft guns are rifled the length of the bore. Rifling is the process where spiral grooves are cut in the inside walls of the gun bore. The projectile fits tightly in these grooves, and a spinning motion is imparted to the projectile as it moves down the bore. The rifling is usually constructed so as to give the projectile a clockwise rotation as

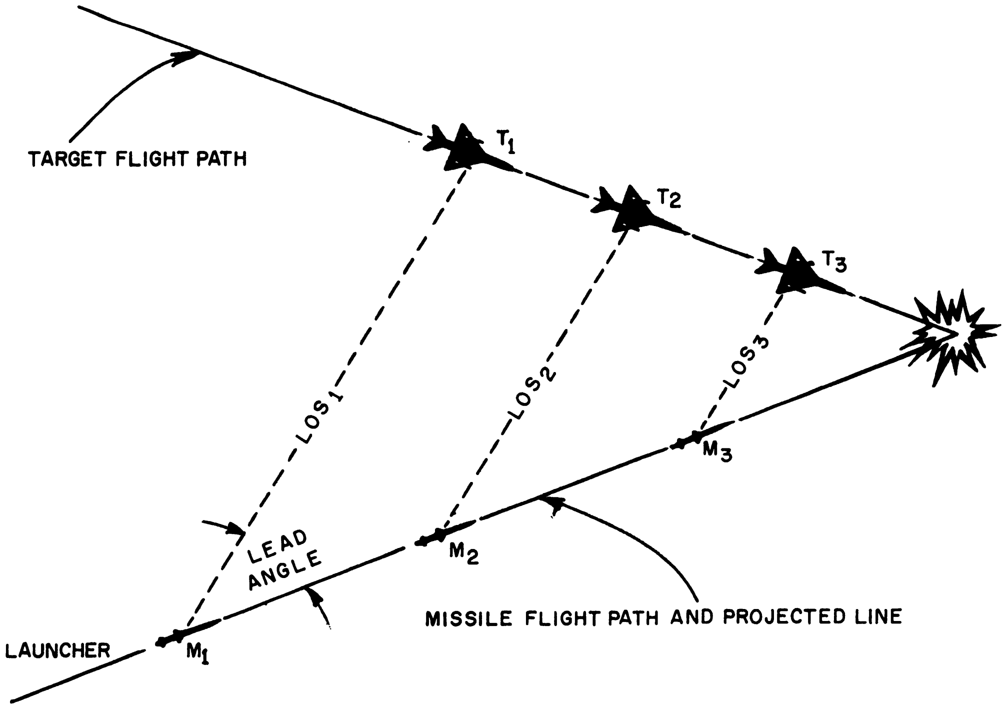

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Figure 8-1.—Lead angle and projected line of a weapon to a target.

viewed from the rear of the gun. The effects of this spinning motion is discussed later in this chapter.

Exterior ballistics is the branch of ballistics with which the AQ is most concerned. However, to fully understand exterior ballistics, the term trajectory must first be mastered. Trajectory may be defined as the curve a projectile describes in space as it travels to the target—for guns it is from the muzzle to the first point of impact; for rockets and missiles the actual ballistic trajectory is that portion of the distance to the target under free flight (after burn time); and for bombs it is from the time of release to the time of impact.

The determination of the trajectory of a projectile with certain physical characteristics and velocity forms the primary problem of exterior ballistics. The primary concern of the AQ is the factors which determine the trajectory of projectiles in air-to-air and air-to-ground attack problems.

FACTORS AFFECTING TRAJECTORY

In the following paragraphs the projectile described in the majority of the examples is that of a gun. However, most of the forces that affect the gun projectile also have the same effect on the bomb, rocket, or missile during free flight. Some of the factors considered have more effect than others, but they must all be taken into account if an attack on a target is to be effective.

Gravity

Gravity is one of the major factors, since it starts acting on the projectile as soon as it is free in the air. The gravity drop of a projectile in flight varies during time of travel. The longer a projectile travels from the gun to the target, the longer gravity influences it. The time of travel will vary with projectile speed and distance to the target. Therefore, the longer the distance to the target and the slower the projectile, the greater the gravity drop.

Gravity drop is computed by the formula

$$s = 1/2\ gt^2$$

where

s = the distance traveled

g = the acceleration of gravity (about 32 ft/sec/sec)

t = the time of fall in seconds.

This formula was developed for conditions in a vacuum, but is sufficiently accurate for computing trajectories of projectiles in still air.

Consider the case of a projectile leaving the muzzle of a gun and traveling 2,000 yards horizontally in 3 seconds. Ignoring all other factors but the effect of gravity, compute the distance that the projectile would fall.

$$s = 1/2\, gt^2$$

$$s = 1/2 \times 32 \times 3 \times 3$$

$$s = 144 \text{ ft}$$

Thus the projectile would fall 144 feet in 3 seconds. This effect is illustrated in figure 8-2.

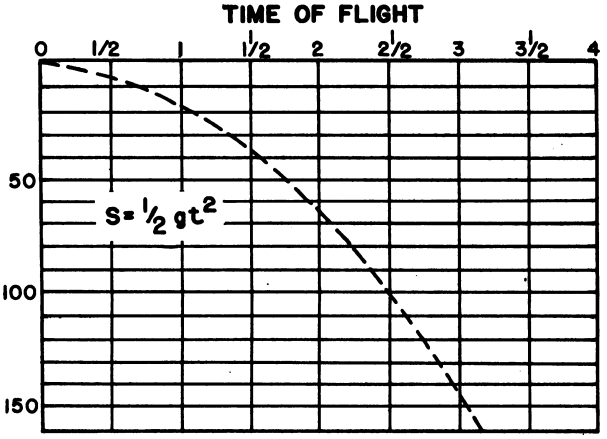

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Figure 8-2.—Gravity drop of a projectile.

From the preceding it should be apparent that the weapon must be elevated to hit a target that is in the same horizontal plane.

Air Density

Air density is one of the factors which contribute to the resistance offered by the air to the flight of the projectile. Cross sectional area and velocity of the projectile are other factors in the determination of the amount of air resistance. The effect of this resistance is the deceleration of the projectile which is more pronounced in the early part of the trajectory. This is due to the higher velocity of the projectile at that time.

It has been found that the denser the air-mass, the greater the friction offered to the projectile; also, the larger the cross sectional area and the higher the velocity, the greater the friction. The longer the distance of travel of the projectile, the greater will be the effect of air density upon the trajectory of the projectile. Therefore, the further the projectile travels, the slower it will travel.

Due to the effects of gravity, a projectile fired horizontally from a high-flying aircraft would start to drop immediately on leaving the muzzle; and the horizontal component of velocity would start to decrease immediately due to air friction. Eventually the projectile would be falling straight down. In falling, the body falls faster and faster until the deceleration due to friction equals the acceleration due to gravity. Then the body continues toward the earth from that point at a constant rate of speed.

Air density is a factor that determines the curve traced by the projectile in its transition from horizontal to vertical flight. The final velocity of the projectile in its downward flight is also a function of air density. The importance of downward velocity can be appreciated when considering the time consumed in the drop of a bomb from any specified altitude. The time of drop is important in the determination of release point.

Among the factors that cause variation in the atmospheric density are variations due to changes in temperature and pressure, variations due to changes in altitude, and variations due to changes in moisture (relative humidity). The density of the atmosphere at a level above the earth's surface depends both upon the density at the surface and the altitude of the given level, since both temperature and pressure decrease with altitude. Because of fluctuations in air density caused by air currents or other influences at different heights, air density at any specific height cannot be expressed as a relationship between altitude and surface density.

The only accurate means of determining air density at any certain altitude is the actual measurement of temperature and barometric pressure. Most aircraft weapon control equipments have the means for continuous measurement of both temperature and pressure.

It is commonly accepted that the retardation of a projectile varies directly in proportion to the density of the air. Therefore, regardless of cause, a given percentage variation in air density has measurable effect upon retardation of the projectile. The amount of retardation due to air resistance will help determine the time of flight of a given projectile for a specified distance.

Figure 8-3 shows three relationships between time of flight of a projectile and relative air density. A study of this graph will be worthwhile not only to show the relationship between the variable factors, but also to familiarize the AQ with the use of this type of graphical representation.

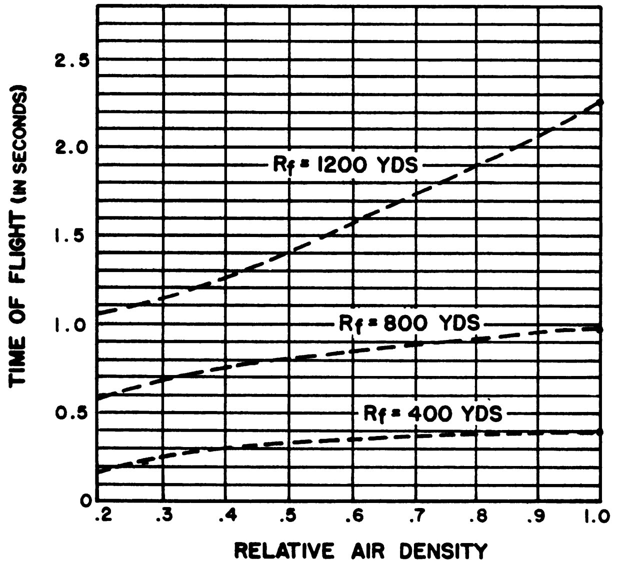

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Figure 8-3.—Relationship between air density and time of flight.

Notice that there are three variable factors in figure 8-3. They are the time of flight along the vertical axis, the relative air density along the horizontal axis, and the future range (R_f). Future range (R_f) is the distance the projectile will travel to the actual point of impact. This distance may be more, less, or the same as the present range (R_p), depending on whether the range of the target is increasing (opening), decreasing (closing), or remaining the same with respect to the launching aircraft. The difference between present range and future range is the amount the range changes during the time of flight (t_f) of the projectile. A change in future range is shown by a change in the actual curve used. All values along the 400-yard R_f curve are indications of time versus relative air density. For instance, when the range is 400 yards and the relative air density is 0.4, the time of flight will be 0.3 second. The curve also shows that when the range is 400 yards and the relative air density is 1, the time of flight will be 0.4 second.

If the range is 800 yards and the relative air density is 0.4, then the time of flight will be approximately 0.75 second. Increasing the future range to 1,200 yards (top curve on graph), an air density of 0.4 results in a time of flight of 1.25 seconds.

An examination of the curves shows that the difference in time of flight for the 400-yard future range is comparatively small across the whole scale of relative air density. At the same time, the difference in time of flight for the 1,200-yard range with the change in air density is considerable. From this it can be concluded that if the aircraft armament control equipment is to be used on short firing ranges, it may not be necessary to continually correct for changes in relative air density. At longer ranges, however, air resistance will affect time of flight and therefore lead angle, which is dependent on time of flight. Compensation is also necessary for the effect of gravity. The greater the air resistance, the longer the time of flight, and the longer the projectile's path is altered by the effects of gravity.

If an armament control equipment is to be used at various air densities and for controlling projectiles with comparatively long future range, the necessity for continuously measuring air density is apparent.

Airspeed and Initial Velocity

The airspeed of the aircraft must also be taken into account when determining the trajectory of a projectile. In forward-firing guns, airspeed is added to the initial velocity of the projectile. Initial velocity is a term often used to indicate the velocity of the projectile at the time it leaves the muzzle (muzzle velocity). The forward motion of the aircraft also affects rockets and missiles at time of launch, but other factors are involved in these problems and are discussed later.

It is easy to see that if a projectile is fired dead ahead, its total velocity (with respect to the ground) would be its initial velocity plus the speed of the aircraft. If a projectile were fired dead astern, the total velocity would be the initial velocity minus the speed of the aircraft.

Since the airspeed of the aircraft affects the velocity of the projectile, it apparently must also affect the trajectory. Airspeed affects trajectory because it is one of the factors that determines the time of flight of the projectile from the gun to the target. As before, the time of flight determines the time the projectile is influenced by the force of gravity.

As an Aviation Fire Control Technician, it would be reasonable to expect a control or automatic device to compensate for the effect of airspeed on trajectory. Such is the situation. Armament control equipment for forward-firing weapons have automatic systems for compensating for airspeed. Automatic means a system that, self-acting, will detect and note changes in aircraft airspeed, and includes these changes in the solution of the problem.

Temperature

Temperature, as such, usually is not a primary factor in consideration of surface gunnery trajectory. Because of the wide ranges of atmospheric pressure and temperature encountered by the aviation gun platform, unlike the surface platform, temperature is one of the factors to be considered in aerial gunnery. The density, pressure, and temperature at 30,000 feet are considerably different than surface conditions.

Effects from changes in temperature are usually secondary in nature, in that atmospheric temperature variations play a part in the determination of one or more of the primary factors of air-to-air trajectory. Because of these wide variations, some types of aviation armament equipment do measure and use atmospheric temperature information in the solution of the trajectory.

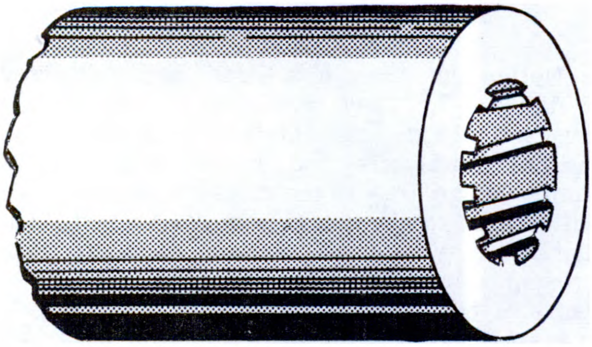
As pointed out previously, air density will change with variations in temperature. One method used to measure air density is to measure both atmospheric temperature and pressure. When both of these factors are measured, they are combined in an electronic circuit which has air density as its output.

Temperature may be measured by several means. One method is to calibrate changes in a liquid pressure utilizing the principle that most liquids contract with a decrease, and expand with an increase, in temperature. Another method is to measure temperature changes by means of an electrical circuit with a resistor sensitive to air temperature. As the resistance of the resistor varies with temperature, it will result in a change in the amount of current in the circuit. The amount of current can be used to actuate a recording or computing device.

Measurement of temperature also plays a part in the determination of true airspeed which is a necessary factor in both air-to-air and air-to-ground trajectory. Airspeed is measured by determining the difference between pitot pressure and static or barometric pressure. Pitot pressure is received from the pitot tube and is the impact pressure of the airstream as the aircraft moves through the atmosphere. This pitot pressure is compared with static pressure to determine airspeed. Because temperature will affect air density and air density affects pressure received from the pitot tube, free air temperature must be applied to change indicated airspeed to true airspeed. True airspeed is the factor of direct importance in establishing the trajectory of airborne projectiles.

Gyroscopic Action

As previously mentioned, all aircraft guns are rifled the length of the bore in order to impart a spinning motion or rotation to the projectile. (See fig. 8-4.) This spinning stabilizes the projectile in flight. The grooves and lands of the rifling are constructed to give a



AQ.391

Figure 8-4.—Aircraft guns rifled bore.

clockwise rotation to the projectile, as viewed from the rear of the gun. Since a rotational motion is imparted to the projectile during its progress down the bore, the projectile in free flight becomes a gyroscope. It attempts to obey all the laws of the gyroscope. The operation of the gyroscope is described in chapter 7 of this manual.

A rotating projectile during flight is subjected to a force which causes it to drift. Drift is the sideward curving of the point of fall from the original plane of fire. (See fig. 8-5.) This deviation is due entirely to the effects set up by the rotation of the projectile. There are other lateral deviations that have an effect on some projectiles. Wind is an example of these deviations. However, they should not be confused with pure drift. While there is no complete agreement as to some of the details, generally there are three accepted causes of drift in an elongated projectile. They are as follows:

1. The gyroscopic action of the rotating projectile.
2. The action of the air adhering to the projectile.
3. The cushioning effect of air banking on one side of the projectile.

The latter two causes are generally thought to have only very minor effects as compared to the first.

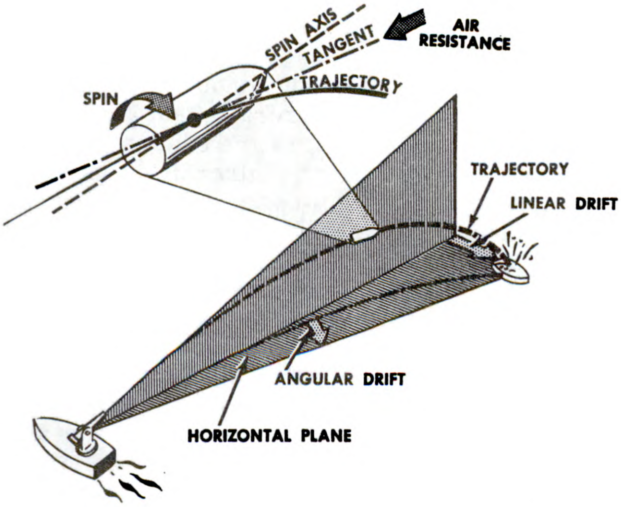


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Figure 8-5.—Projectile drift caused by gyroscopic action

The gyroscopic action of the projectile while spinning in flight tends to keep the projectile's axis in the direction of the line of departure from the gun. However, the center of gravity of the projectile in flight tends to follow the curved path of the trajectory. The instantaneous direction of its motion at any point is that of the tangent to the trajectory. Air resistance opposes the flight of the projectile and works against its underside with greater force than elsewhere as shown in figure 8-5. The air resistance tends to push the nose of the projectile up.

An overturning or tumbling motion results as the center of gravity and an extension of the center of pressure to the axis of the projectile becomes further separated. However, the gyroscopic force of the projectile opposes this upsetting or overturning moment, and tends to keep the axis in the original direction. This gyroscopic moment which opposes the upsetting moment, in accordance with the laws of the gyroscope, causes a precession of the projectile about the direction of the force as it tries to overcome the tendency of the projectile to overturn. Also, according to the laws of the gyroscope, the precessional revolution of a projectile having a right-hand spin must be clockwise when viewed from the rear. This precession moves the nose to the right; and air resistance, working on the left side of the nose, forces the projectile to the right. This motion to the right is drift.

Wind

Some of the preceding effects upon trajectory are reserved for consideration of projectiles propelled from guns. Among these effects are the muzzle velocity and the rotation of the projectile. Others of the previously discussed effects have their influence on all types of projectiles. Gravity and air resistance will affect not only gun-propelled projectiles, rockets, and missiles, but also bombs. However, wind fits into an entirely different category, in that it must be considered in the air-to-ground problem but not in the air-to-air problem. Wind is defined as the motion of the air relative to the earth.

AIR-TO-AIR TRAJECTORY.—Because of the relatively short distances involved and the short time of flight of projectiles in the air-to-air problem, the effects of atmospheric wind are not a factor in the determination of the trajectory.

This may be visualized by considering the wind as a block of air (a frame of reference) containing both the target and the gun. If both the target aircraft and the aircraft containing the gun or rocket launcher are in this mass of air, they will be affected equally and in the same direction when considered with respect to the ground.

If considered only in respect to each other and the mass of air, there will be no change in their relationship caused by the movement of the airmass. As an analogy, consider a fly in a closed, moving automobile. The movement of the automobile does not affect the relationship of the fly and any object in the interior of the automobile. In the same manner, any projectile propelled from an aircraft toward another airborne target will be unaffected by the movement of the airmass through which the projectile is moving. This lack of effect will not be true for projectiles launched from surface platforms or from airborne platforms and directed against surface targets.

AIR-TO-GROUND TRAJECTORY.—In bombing ground targets from an aircraft, the bomb is released without any propelling force. As it travels through the air, the forces of gravity and air resistance will act upon it. The initial velocity of the bomb is the true airspeed of the aircraft. The trajectory of the bomb will then be determined by the effects of gravity and air resistance. If a wind is blowing, it will also act upon the bomb and will cause it to drift with respect to the ground. This drift may become a serious factor in bombing.

In order that the effects of wind on a bomb trajectory will have more meaning, a brief discussion of some of the aspects of the bombing problem are presented here. A more complete discussion of the bombing problem is included in a later chapter of this manual.

To facilitate the understanding of a bomb's trajectory, consider an imaginary situation—the release of a bomb in a vacuum from an aircraft. The motion of the bomb imparted by the moving aircraft, plus the time of fall, determines the range. Range is the total horizontal distance the bomb moves forward from the place of release until impact. In this theoretical case, there will be only two forces acting on the bomb. These are gravity and the motion of the aircraft. The bomb will be directly beneath the aircraft at the time of impact.

Since it is necessary to consider air resistance in order to deal realistically with the problem of trajectory, it is necessary to cover the problem of trajectory in air. There will then be four forces acting on the bomb. These forces are the force of gravity, the air resistance in a vertical direction which opposes the pull or force of gravity, the motion imparted to the bomb by the aircraft, and the air resistance in the horizontal direction which opposes the forward motion of the bomb. The air resistance in the vertical direction causes the bomb to decrease in velocity at any instant during its fall, and thereby increases its time of fall. The longer the time of fall, the longer the bomb will be subject to the force of the wind. Air resistance in the horizontal direction causes the bomb to trail behind the vertical of the aircraft. In other words, when the bomb reaches the point of impact, it will not be directly beneath the aircraft.

With a constant airspeed and course, the horizontal distance that the bomb has lagged behind the aircraft at the instant of impact is called trail. The amount of trail is governed by the aircraft's airspeed at the time of release, and the length of time the air resistance acts on the bomb. The amount of air resistance is determined by the air density (hence, the altitude) and the bomb's physical characteristics (shape, weight, and size). It is important to note that these three factors which determine trail—airspeed, altitude, and bomb characteristics—are unaffected by the presence of wind. Therefore, trail is independent of wind and has the same value in a headwind or a tailwind that it has in still air. Trail and range are shown in figure 8-6.

The principal effect of winds along the line of the heading of the aircraft (that is, either headwinds or tailwinds) is the change made in the closing speed of the aircraft. Assuming that the target is stationary, if there is no wind, the closing speed is equal to the true airspeed of the aircraft. In a headwind, the closing speed equals true airspeed minus wind velocity. In a tailwind, closing speed equals true airspeed plus wind velocity. The trail value remains unaffected and is the same for all three cases. The reason for this is apparent when it is realized that the closing speed of the bomb is the same as that of the aircraft at the moment of release.

When the aircraft is headed either directly into the wind or downwind, its course over the ground is the true course flown. In other words, it makes its own course good over the

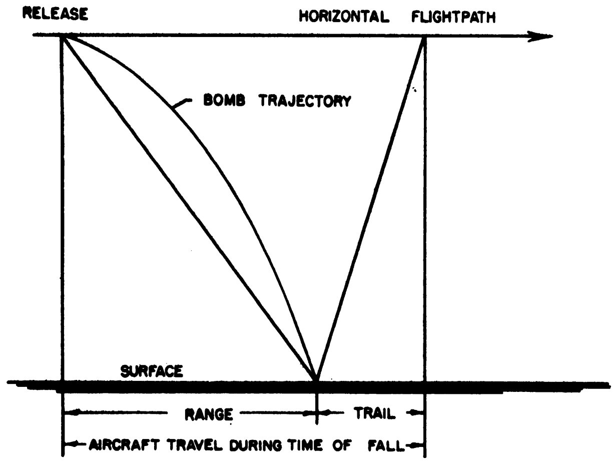

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Figure 8-6.—Horizontal bombing trail and range.

ground. In all other instances, the course steered will not be the actual course over the ground. Therefore, there will be an angle formed between the course the aircraft is steering and the course it makes good over the ground. This angle is called the angle of drift and is shown as the angle between the aircraft heading and aircraft path in figure 8-7.

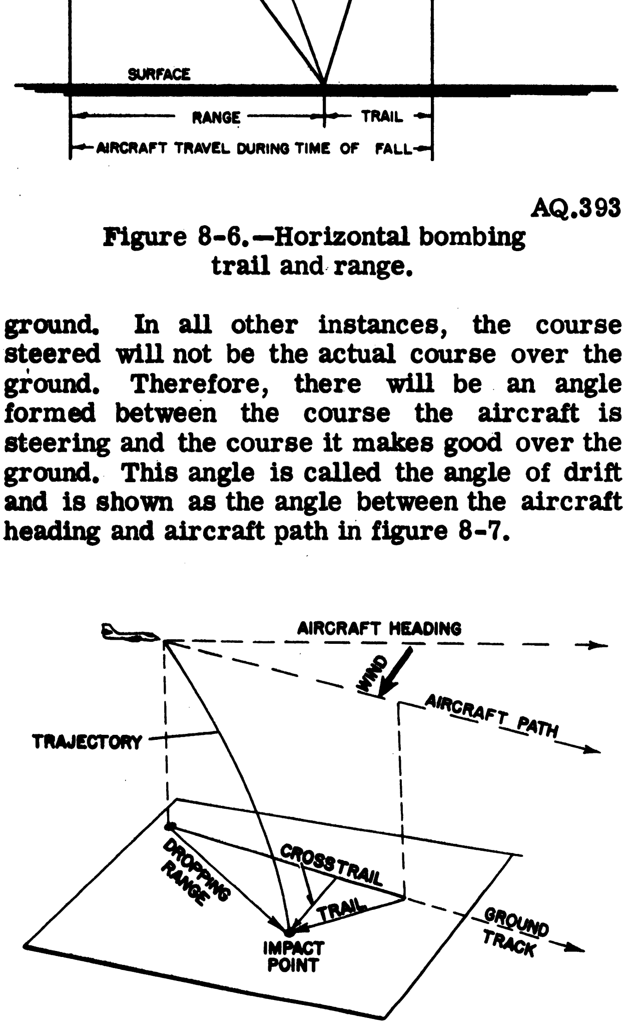

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Figure 8-7.—Effects of crosswind on bomb trajectory.

Associated with the angle of drift is another factor called crosstrail. (See fig. 8-7.) Crosstrail is the distance the bomb falls toward the downwind side of the target due to the combination of drift angle and the natural trail of the bomb. To compensate for crosstrail, it is necessary for the aircraft to fly a course which takes it to the upwind side of the target a predetermined amount or distance which corresponds with the amount of crosstrail existing.

Wind will also affect the trajectory of a rocket fired at a surface target. The rocket's time of flight for a given range determines, in part, the extent to which the trajectory will be affected by wind. As with other projectiles, the time of flight will be determined by the velocity, the range, and the air resistance.

The influence of wind on an aircraft at the firing altitude causes it to drift. This motion is retained by the rocket when it is fired. The magnitude of drift for a rocket with a given time of flight varies with direction of the wind relative to the aircraft's heading, wind force, and angle of dive.

In computing the aiming allowances for wind, it is assumed that the air moves as a body with the same speed and direction at all altitudes. The effect of wind can be visualized by considering the air as a stationary mass and the earth as moving with the velocity of the wind. Thus it is obvious that the wind will cause the impact point on the earth to move a distance equal to the product of the time of flight and wind velocity. This also serves to illustrate that the aiming allowances for wind and target motion are the same magnitude.

Because wind does affect the trajectory of the rocket in its course from aircraft to target, aiming allowance must be used to compensate for the effect. A crosswind deflects a rocket the full amount of wind velocity multiplied by the rocket's time of flight, regardless of dive angle. Compensation for a crosswind then requires full wind aiming allowance.

An oblique wind (fig. 8-8) is defined as one from such a direction that its apparent path in the sight is midway between the horizontal and vertical crosslines. An oblique wind exerts only part of its force in changing the course of the rocket. The shallower the dive, the less the rocket is affected and the less aiming allowance required. The steeper the dive, the greater the effect and aiming allowance approaches that for a crosswind.

Angle of Departure

As previously mentioned, trajectory is the curve a projectile describes in space as it

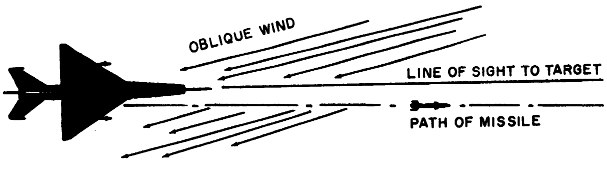

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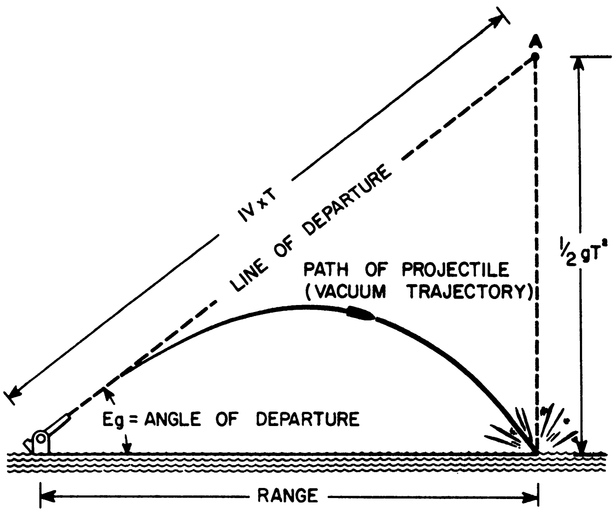
Figure 8-8.—Effect of oblique wind on path of a rocket.

travels through the air on its way to the target. The origin of a trajectory is the position of the center of gravity of the projectile at the instant it is released. The tangent to the trajectory at its origin is known as the line of departure. The angle that the line of departure makes with the horizontal is the initial angle of inclination of the trajectory and is called the angle of departure. These terms are illustrated in figure 8-9.



AQ.396
Figure 8-9.—Path of projectile (vacuum trajectory).

Consider once again the imaginary situation of a projectile fired in a vacuum. The trajectory is shown in figure 8-9. The projectile will have two motions. One is the motion along the line of departure at a speed equal to the initial velocity, and the other is the effect of gravity—a falling motion straight down at a constantly accelerating speed. At the instant the projectile leaves the gun, it will be falling. It falls slowly at first, so most of its motion will be upward and forward along the line of departure. As it travels farther, it will fall faster, until the falling speed equals the upward speed along the line of departure. This is the highest point or the middle of the projectile's path. As it continues to fall, gravity will be pulling it down faster than momentum (always constant in a vacuum) is carrying it up. Its path will curve downward more and more steeply, until it finally hits the surface.

The distance from the weapon to the point where the projectile hits the surface is the range of the weapon at that particular elevation. The range will change at different elevation angles. When the tilt of the line of departure is moved upward, the projectile's initial velocity tends to carry it higher. Thus, the projectile will have farther to fall before it hits the ground. The reason is that it takes longer for the projectile to fall to earth, and during this longer time it has a chance to go farther forward.

As angle E_g (fig. 8-9) is increased and the gun is elevated, the projectile is given more upward movement. Of course, it is also given less forward movement. If this angle is increased above 45°, the time the projectile is traveling will continue to increase, but the forward movement will be so much slower that, even in the longer time, the projectile will not go as far. Obviously, if the gun is directed straight up from a stationary platform, the range will be zero. Maximum range is obtained (in a vacuum) at an elevation of 45°. Some typical trajectories are shown in figure 8-10. Notice how the range varies with the different elevation angles.

As would be expected, the trajectory of a projectile is considerably altered by its travel through air. A comparison of the air trajectory and the vacuum trajectory is shown in figure 8-11. Air alters the shape of the trajectory in several different ways. The striking velocity of the projectile no longer equals its initial velocity. The angle of departure no longer equals the angle of fall. Range is greatly decreased. Also, as pointed out previously, the projectile acts like a gyroscope. All these factors must be considered in aiming the gun. Some of the latest equipments measure and compensate for each factor. Other types of equipment compensate for some factors but not all of them.

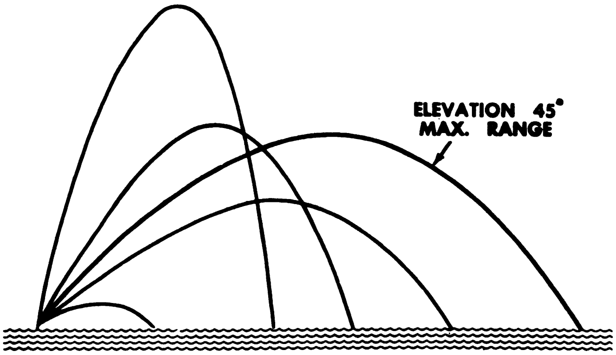


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Figure 8-10.—Effects of elevation on range in a vacuum.

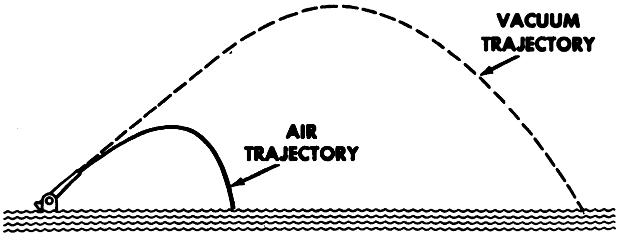

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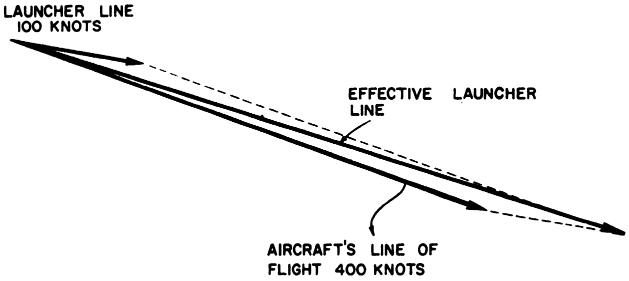
Figure 8-11.—Vacuum and air trajectories.

For example, an accelerometer can be used to measure the g pull on the projectile at the time of release. If the angle of departure varies, the effect of pull of gravity on the projectile will vary. Actually the force of gravity is the same regardless of the angle of departure, but the effects of gravity will change with the angle of departure. The reason for this, as previously explained, is that the trajectory is the result of two motions—the forward motion and the downward motion. If the forward motion is reduced, then the trajectory will be more influenced by the downward motion—gravity. Thus, the accelerometer measures the g pull on the projectile and modifies the gravity lead computation to compensate for this g pull.

The angle of departure is also important in determining the flightpath of air-launched rockets. The angle of the launcher in respect to the aircraft armament datum line will determine the angle of departure of the rocket from the aircraft. The armament datum line is the longitudinal reference line fixed relative to the aircraft by boresight fittings provided for that purpose. In most systems, means are provided to compensate for any angular difference in the launcher line and armament datum line.

The rocket's actual line of departure is a compromise between directional forces. One is the rocket's own motion, weak at first, along the launcher line. The other is the aircraft's motion along its line of flight, a strong force also imparted to the rocket. The actual direction taken by the rocket is the resultant vector of these two forces, known as the effective launching line. (See fig. 8-12.)



AQ.399
Figure 8-12.—Effect of launching line.

The aircraft's attitude along the line of flight, its angle of attack, is particularly significant in aiming rockets. It influences the position of the effective launching line and the angle between the zero line of sight and the effective launching line. The three types of attitudes are as follows:

1. Zero angle of attack.
2. Noseup or positive angle of attack.
3. Nosedown or negative angle of attack.

The effective angle of departure of a rocket is also going to be influenced by the effect of the angle of dive. The steeper the dive, the less the vertical pull of gravity affects the rocket's trajectory and the smaller the aiming allowance for vertical drop. When the effective launching line points straight down, the force of gravity simply adds to the impetus of the rocket along this line. As the effective launching line moves toward the horizontal, the more gravity deflects the rocket from its initial path, and the larger the sight angle required.

Rockets tend to follow the direction of flight of the aircraft, while aircraft gun projectiles travel in the direction of aim. The aircraft gun projectile travels close to its direction of aim because the muzzle velocity is so much greater than the speed of the aircraft that the effect of the latter upon the motion of the projectile is slight. The fins of a rocket, on the other hand, tend to aline the rocket with the airflow. Since the launching speed is small compared to the speed of the aircraft, the rocket is quickly alined with the resultant airflow; that is, almost completely in the direction of the line of flight of the aircraft.

The rocket trajectory is characterized by considerable curvature compared to the relatively flat trajectory of an aircraft gun projectile. Not only does the longer time of flight lead to a greater gravity drop but, in addition, as the rocket falls, the fins tend to aline it along the trajectory, so that there is also a component of the jet force downward, contributing to the normal gravity drop. The consequent large curvature means that the sighting allowance required in aiming and its variation with dive angle are much greater for rockets than for aircraft guns.

Missiles, such as Sparrow and Sidewinder, are provided with a guidance system, and small errors in aiming can be corrected during flight to the target. The missile is actually a pilotless aircraft, and its flight is governed by the rules of aerodynamics. Although some of the factors which determine the trajectory of the gun projectile, rocket, or bomb also affect the missile, the flight characteristics of the missile must be included in determining its trajectory.

SELF-PROPELLING FORCES OF ROCKETS AND MISSILES

As can be seen, the problem of firing rockets from an aircraft is considerably more complicated than that of firing guns. These complications stem mainly from the ballistics of the rocket and the method of launching. These two factors are not easily separated since the trajectory of the rocket depends upon the manner in which it is launched as well as other factors. One of the main influences on the trajectory of the rocket is the fact that it is self-propelled.

As stated previously, the gun projectile is hurled forward by the pressure of gases expanding in the firing chamber. It has top speed when it leaves the muzzle. A rocket, which is propelled by jet force of gases produced by burning the propellent charge it carries, starts rather slowly. Because a rocket starts slowly, has a long flight time, and tends to turn downward due to fin and the jet effects, it has a very curved trajectory.

Unlike a gun, even the largest rocket exerts no recoil on its launcher. The back pressure is absorbed in the open air. The only purpose of the launcher is to hold the rocket in place and point it in a given direction until fired. Because of the "no recoil" feature, an aircraft can fire as large or as many rockets as it can carry. A fighter aircraft's salvo of rockets can be equivalent to a destroyer's salvo power.

It is instructive to note the differences, related to the methods of propulsion, in the trajectory of rockets and aircraft gun projectiles. These differences are as follows:

1. The velocities.
2. The direction of flight.
3. The trajectory curvature.

Rockets are slower. The velocity of the fastest rocket used at present in forward firing is considerably less than that of an aircraft gun projectile. Furthermore, it takes the rocket a relatively long time to reach its maximum velocity, whereas the aircraft gun projectile has its maximum velocity as it leaves the muzzle. The consequent longer time of flight of the rocket to a given range means that allowances for target speed and wind are much greater than in the case of aircraft gunfire.

METHODS OF INSERTING BALLISTIC INFORMATION

Various weapons systems are provided with different means of inserting ballistic information into the computation when computing for the proper lead. In some systems a separate plug-in unit is designed for each of the different types of armament. Others have this information recorded on the magnetic tracks of a memory drum in the computer. Provisions are made in some systems for manual insertion through a keyboard arrangement, which is an integral part of the system. No matter which method is used, the weapons system will have available all the necessary ballistic information to compute the point-of-aim for any of the different types of armament that the aircraft is designed to carry. These include air-to-air and air-to-ground types.

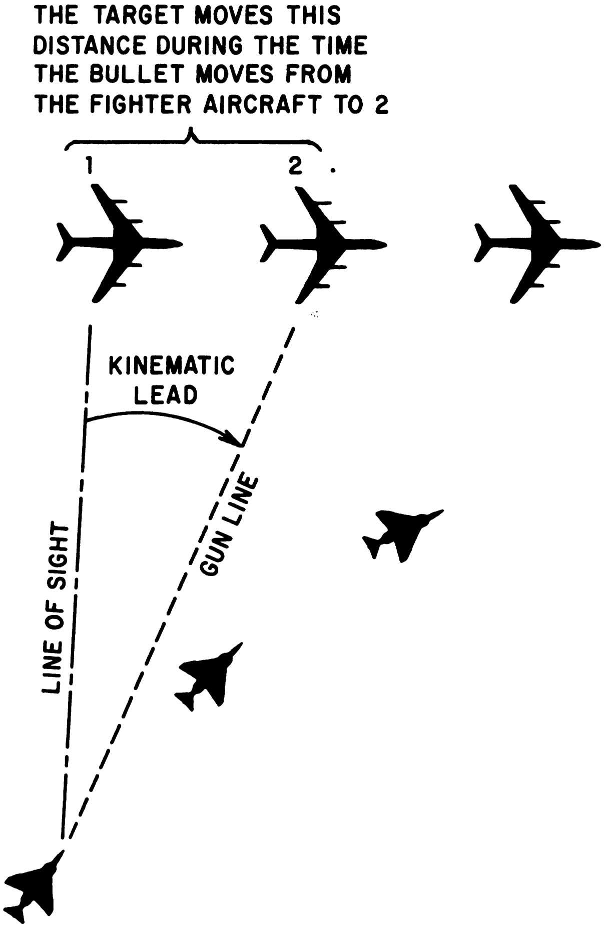
Although the AQ is not required to determine the factors incorporated, the knowledge of how these factors influence the trajectory of the projectile will make him aware of the necessity of making sure the proper information is inserted. Further, the exacting care in making adjustments and in maintenance should be apparent.

SOLVING THE PROBLEM

In the preceding section of this chapter, all of the factors presented contributed to the trajectory (movement) of the projectile. Compensating for these factors is fairly simple and in some cases, such as a tail chase or a head-on attack, would produce all the lead angle required to hit the target. However, in many cases involving fast moving aircraft, a head-on or tail chase attack may be undesirable or impossible and some type of deflection shooting is necessary. For deflection shooting, solution of the ballistic lead angle produces only a portion of the total lead angle required.

TOTAL LEAD ANGLE

Just as the duck hunter made allowance for the distance the bird traveled after he fired, so does a fighter pilot have to make an allowance for target motion. This allowance is in addition to the ballistic lead allowed, and is called kinematic lead angle. This lead angle is required because in deflection shooting the line of sight must be turned continuously to keep it on the target. Line of sight can be described as the direction along which the pilot (or tracking radar antenna) of the attacking aircraft looks at any instant when observing the target, as illustrated in figure 8-13. A second line is indicated as the gun line. The angle formed between these two lines is known as kinematic lead and is required whenever the line of sight must turn to remain on the target. The total lead angle then is the combination of ballistic lead and kinematic lead. The word kinematic is a term used to describe the science that treats motions when considered in themselves. Concern in this course is not with the science itself, but with some of the ideas which have been developed in the science. As can be seen, accurate measurement of the total lead angle is an absolute necessity. This is done by the use of what is termed the mil measurement.


THE TARGET MOVES THIS DISTANCE DURING THE TIME THE BULLET MOVES FROM THE FIGHTER AIRCRAFT TO 2
1
2
KINEMATIC LEAD
GUN LINE
LINE OF SIGHT

AQ.400

Figure 8-13.—Kinematic lead angle.

The standard unit of deflection used in naval aviation weaponry is the bombing mil. The bombing mil is established as an arc, the length of which is 1/1000 of its radius. The radius represents range or bombing altitude, while the length of the arc represents the difference between where the projectile is pointed at launch and its actual point of impact. (See fig. 8-14.) Thus, a 1-mil angle would mean that at a 1,000-yard range the point of impact would be 1 yard from the point at which the projectile was pointed when launched.

Lead angle of deflection is usually computed in mils. A lead angle of 10 mils for a target range of 1,000 feet would result in a difference of 10 feet (at the target) between the line of

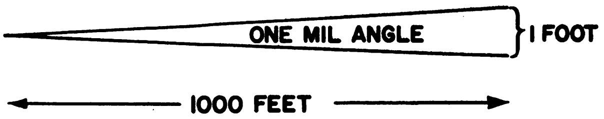


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Figure 8-14.—Diagram of the bombing mil angle

sight and the centerline of the launcher or gun bore.

PURSUIT AND COLLISION CURVES

The problem of determining pursuit curves has a long historical background. The military aspects of the problem were brought into prominence in connection with aerial combat wherein one aircraft is attacked by another possessing guns capable of being fired in a fixed direction only. In order for the one aircraft to keep the other under continuous fire, it must fly some kind of a pursuit course. The problem appears again with the invention of homing missiles which continuously change heading under radio, optical, or infrared guidance.

In general, a fixed weapon fighter flies one of two courses when attacking a target. These are the pursuit course and the collision course. A pursuit course (fig. 8-15) is flown when the firing aircraft maneuvers in such a manner as to be in a position to fire upon the target continuously throughout the run. In order to produce hits, the fighter is constantly pointing ahead of the target by the correct lead angle, and a projectile fired at any time (within range) can be expected to score a hit. In the process of tracking the target, the pilot must fly a curved path, the curvature depending upon the range, relative target speed, angle of approach to the target, and aircraft's angle of attack.

On this course the weapons are within range of the target and are tracking it for several seconds; consequently, many rounds of ammunition may be fired. Therefore, the pursuit course is used when employing multiple projectiles, such as in aircraft gunfire.

If this pursuit course is carried through, the fighter will eventually be in a tail chase.

The collision course (fig. 8-16) is a straight-line course in space (assuming target velocity to be constant) that positions the fighter so that its projectiles, fired at one point on such a line, will score a hit. There is only one point on such a line where firing will be effective. Therefore, the collision course is used when a single salvo of projectiles, such as rockets or guided missiles, is employed. These usually discharge a large amount of ammunition almost instantaneously, thereby increasing the prospects of a kill.

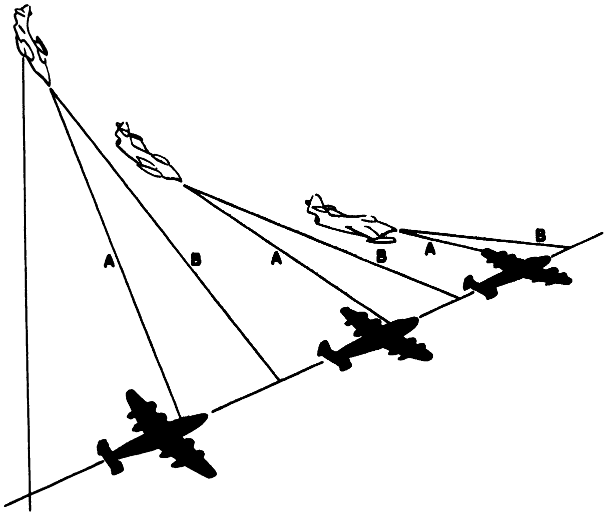

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Figure 8-15.—Typical pursuit course.

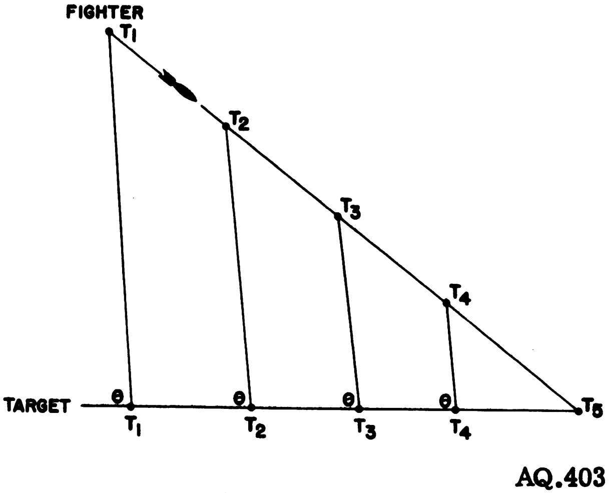

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Figure 8-16.—Collision course.

The pursuing aircraft flies on a prescribed course at a prescribed speed. These are determined by the computers after the target is tracked. At the proper time (T_1), the missile is automatically released. The missile flies in a collision course with the target, bearing a constant angle from the target at all instants of time (T_2, T_3, T_4). Finally, at time T_5 it strikes the target, assuming that the missile maintains a constant velocity.

The chief advantage of the collision course is that the fighter flies a straight-line flightpath. This enables the fighter to reach the firing point faster and break away from the area of defensive fire sooner and with less maneuvering. Note that at the moment of firing from a lead collision course, the fighter is at one position of a pursuit course and could transfer to a pursuit course.

As previously mentioned, one of the elements in the solution of the fire control problem is the effect of the relative motion between the aircraft and its target. Two of the main considerations in determining the effect of this relative motion are the change in distance and the change in angle. This section is concerned with an examination of the rate of change in distance (range) or linear velocity and acceleration.

While the idea of range is generally well known, the concept of rate of change of range does not enjoy such familiarity. As a method of analysis, the two terms are first defined.

Rate is the amount or degree measured in proportion to something (in this case—time), while range is the distance between the aircraft and its target. A combination of these two definitions must result in range rate being the change in distance as measured in proportion to time.

Linear Velocity

Although often freely interchanged, the words speed and velocity do not have the same meaning. Speed is a reference to the distance covered in a unit of time and is a scalar quantity. Velocity involves both speed and direction, and is a vector quantity. Velocity, then, is the time rate of change of position.

If an aircraft is flying east at 300 miles per hour (mph), its speed would be 300 mph. The velocity of the aircraft would be 300 mph east. Because velocity is a vector quantity with magnitude and direction, there is more than one way to change velocity. The speed can be changed, the direction can be changed, or both can be changed. (See fig. 8-17.)

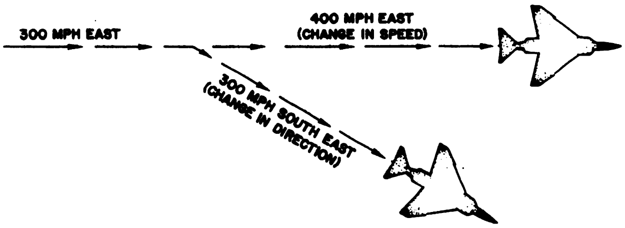

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Figure 8-17.—Change in velocity.

Velocity is uniform only when equal distances along a straight line are traveled in equal intervals of time. Symbolically, if d is the distance covered in time t, the velocity is

$$v = \frac{d}{t}$$

How long does it take an aircraft traveling at 200 mph to travel 300 miles?

$$t = \frac{300 \text{ mi}}{200 \text{ mph}} = \frac{3}{2} \text{ hr} = 1 \text{ hr } 30 \text{ min}$$

Remember that both speed and direction are involved in velocity. When substituting in the velocity equation, however, only magnitude of velocity is used.

Relative Velocity

In discussing velocity, it is necessary to have a point of reference. If two aircraft are traveling with the same velocity (300 mph north) and are separated by 5 miles of distance, they obviously will never make contact. But consider a situation where one aircraft is flying north at 300 mph and the other in front is flying north at 200 mph. The faster of the two will overcome the slower with a rate of change of range of 100 mph. Now consider one aircraft flying south at 300 mph and another flying north at 300 mph. What is the relative velocity between the two or the rate of change of range? ANSWER: 600 mph.

If the aircraft flying north was taken as the point of reference, then the other aircraft would have a relative velocity of 600 mph south.

In discussions on the fire control problem, the aircraft is often considered as a gun platform. If such is the case, then the velocity of a target would always be relative to the gun platform.

Acceleration

When the velocity of a moving body increases continuously as the motion proceeds, the body is said to move with accelerated motion or to have an acceleration. For example, suppose that the velocity of an automobile increases steadily from 30 mph to 60 mph in 3 minutes. During each minute of the 3-minute interval, the velocity increases by 10 mph per minute. Therefore, the velocity increases at the rate of 10 mph per minute. This rate of change of velocity with respect to time is called constant acceleration. Acceleration may be either positive or negative—positive acceleration meaning an increase in velocity, and negative acceleration meaning a decrease in velocity. Negative acceleration is also called deceleration or retardation.

The equation for average acceleration is

$$a = \frac{V_2 - V_1}{t}$$

where a is acceleration, V_1 starting velocity, V_2 final velocity, and t elapsed time. The above equation is true only for uniform changes in velocity.

One of the most common examples of motion with a nearly constant acceleration is that of a body falling toward the earth. In a vacuum, all bodies—regardless of their size or weight—fall with the same acceleration (32 feet per second per second near the earth's surface). Because of its effect on a projectile in flight, the force of gravity must be taken into account in the resolution of the fire control problem.

Angular Velocity

The concepts of velocity and acceleration that have been presented so far have dealt solely with linear motion. As was pointed out previously, relative motion is composed of both linear motion and angular or rotational motion. The ideas of linear velocity and acceleration presented in the preceding section have their exact parallels in rotational motion. In both cases, displacement with respect to elapsed time is known as velocity, and a change in velocity with respect to time is known as acceleration.

Although the equation of angular motion takes on a simpler form when the angular velocity is expressed in radians per second, the expressions revolutions per second (rps) or revolutions per minute (rpm) are also commonly encountered. There are 2π radians in one revolution. The number of radians per second, therefore, equals 2π times the number of revolutions per second or $2\pi/60$ times the number of revolutions per minute.

The number of revolutions per second is usually referred to as the frequency. The quantity angular velocity $2\pi f$ is represented by the symbol ω (omega). Therefore,

$$\omega = 2\pi f$$

There are two common methods for measuring angular velocity. In the first method, a revolution counter is held against the end of a rotating shaft and the number of revolutions during a time interval is noted. The time and the displacement are thus measured and the ratio gives the angular velocity. In the second method, the angular velocity is measured directly by a tachometer. Most tachometers, however, are calibrated in revolutions per minute rather than in radians per second. The common automobile speedometer is a good example of a tachometer calibrated in miles per hour.

The preceding section on linear motion shows that if a body is moving with constant velocity, the distance covered in any period of time is the velocity multiplied by the time. An exact analogy occurs in circular motion. Let θ (theta) be the angle or the angular distance covered. Then the equation for the angular distance or degrees through which the body rotates is

$$\theta = 2\pi ft = \omega t$$

where θ is the total angular distance covered expressed in degrees, revolutions or radians; $2\pi f$ or ω the angular velocity in degrees; revolutions, or radians per second; and t the elapsed time in seconds.

Angular Acceleration

Newton's first law of motion states that "every body continues in a state of rest or of motion in a straight line unless compelled by external force to change that state." Thus, a body is accelerated when a continuous external force is applied to the body either at rest or in uniform motion. If the direction of the external force is in line with the motion of the body and in the same direction, the body is speeded up (accelerated). If the direction of the external force is in line with the motion of the body and in the opposite direction, the body is slowed down (decelerated). If any component of the external force is not in line with the motion of the body, the body is turned from its path.

Most individuals have at some time performed the experiment of tying a weight to a cord and whirling it in a circle. While the object is revolving, there is a pull exerted on the individual's hand. Conversely, the individual's hand must exert an inward pull on the object. This pull of an object whirled around in a fixed circle is due to radial acceleration, as it is called in physics.

If the weight starts from rest and in t seconds acquires an angular speed of ω radians per second, assuming that the process has been done at a uniform rate, it can be said that the angular acceleration α (alpha) expressed in radians per second is

$$\alpha = \frac{\omega}{t}$$

NOTE: This is angular acceleration and not the acceleration of the weight around the circumference of the circle.

According to Newton's second law, a force must be exerted on a moving object to make it follow a curved path instead of a straight path. The necessary force is proportional to rate of change of momentum produced. This force is in the same direction as radial acceleration, which is inward. It is called centripetal force. The name "centripetal" literally means center-seeking. It is the pull which the individual's hand must exert on the string. The opposite or reaction force to this is centrifugal force which means center-fleeing.

Recall that velocity is a vector and that a vector has magnitude and direction. If a body moves at a constant speed around the circumference of a circle, its velocity (v) is always varying because the direction of the velocity is changing. As stated previously, it can be shown that acceleration is toward the center and that the centripetal acceleration (a) is equal to v^2/r, where v is the velocity tangent to the circumference and r is the radius of the circle.

By substituting v^2/r for a in Newton's second law (F = ma), the equation becomes:

$$F = \frac{mv^2}{r}$$

This equation is given to point out the factors influencing the centrifugal force. Recall that centrifugal force is opposite and equal to centripetal force. Notice that the force of centrifugal action increases directly with the mass and as the square of the velocity. Thus, an increase in velocity of three times produces nine times the centrifugal force.

In aviation, the acceleration produced when an aircraft pulls out of a dive is an extremely important factor. Electronic equipment must be designed to withstand the physical strain of centrifugal force in aircraft and guided missiles. The peak acceleration due to a quick turn or pullout is measured by an accelerometer and is indicated in g's. A 10-g pullout from a dive, therefore, means that the acceleration is 10 times that caused by gravity, thus a 5-pound weight would pull with a force of 50 pounds in a 10-g dive. Electronic equipment for use in guided missiles must not produce distortion when accelerated up to 40 g's.

Further application of centrifugal force is found in the gyroscope. The gyroscope is the basic element in such instruments as the gyrocompass, the gyropilot for aircraft and ships, and certain types of weapons systems.

RELATIVE MOTION

The actual path in space traced by an aircraft as viewed by an imaginary observer at some fixed point in space is, in general, a very different appearing curve when viewed from another aircraft. In figure 8-18, let the horizontal curve (right to left) represent the path of a target aircraft as viewed by this spatial observer. The vertical curve (bottom to top) represents that path of fighter aircraft or airborne gun platform. The t numbers on both curves represent corresponding intervals of time. The distance or range at each interval of time is represented by r. The angle τ (tau) measured from the gun platform to the gun-target line, is called the angle-off of the target or simply angle-off.

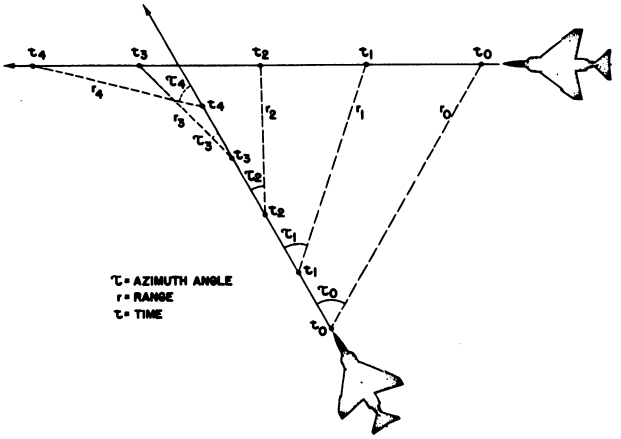

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Figure 8-18.—Air course of target aircraft.

The path of the target as viewed by the observer is called the "air course," while the path of the target as viewed from the gun platform is spoken of as the "relative course." Figure 8-18 shows the air course of both target and gun platform. These curves represent the actual motion in space. Notice as time progresses, the range becomes smaller, and the angle decreases and then changes from right horizontal to left horizontal.

In the solution of the air-to-air fire control problem the actual course of either target or gun platform is of much less importance than the relative course. The reason for this is that the correct lead angle for obtaining a hit depends upon the relative motion between the two aircraft.

Because the relative course is the important course, consider the path of the target relative to the gun platform. This path may be determined by using a gun platform as reference and measuring the range angle-off of the target for several points. A smooth curve is then drawn through these points as shown in figure 8-19.

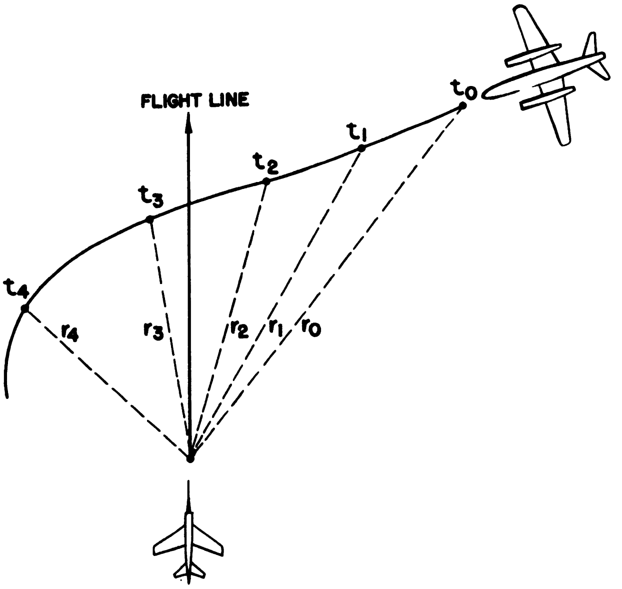

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Figure 8-19.—Relative course of target aircraft.

In figure 8-19, r_0 distance is the same as the r_0 distance in figure 8-18, as are all corresponding distances. Angle τ_0 in figure 8-18 is the same as the angle formed between the flight line and the line from the reference to τ_0 in figure 8-19. The only difference between the two figures is the reference point. The actual path in space traced by an aircraft as viewed by an imaginary observer at some fixed point in space is, in general, a very different appearing curve when viewed from another aircraft. Figure 8-20 shows both the air and relative courses of a fighter pursuing a bomber.

FUTURE TARGET POSITION

The ability to determine the future position of the target when the projectile strikes is in essence the solution to the problem. There are many factors which contribute to the determination of this future position. To facilitate understanding of this problem, consider the following three general cases.

First consider the hypothetical case of a ballistically perfect stationary gun firing at a stationary target in a vacuum and where the projectile is not subject to the effect of gravity. The problem in this case is to aim the gun so that the axis of its bore intersects the target. Since there is no force acting on the projectile except that which expelled it from the gun, it will travel along a straight line and hit the target.

In any actual case, such as firing at a stationary target on a target range, the effects of gravity and sometimes of wind are exerted on the projectile and cause it to depart from its straight-line flight. Gravity causes the

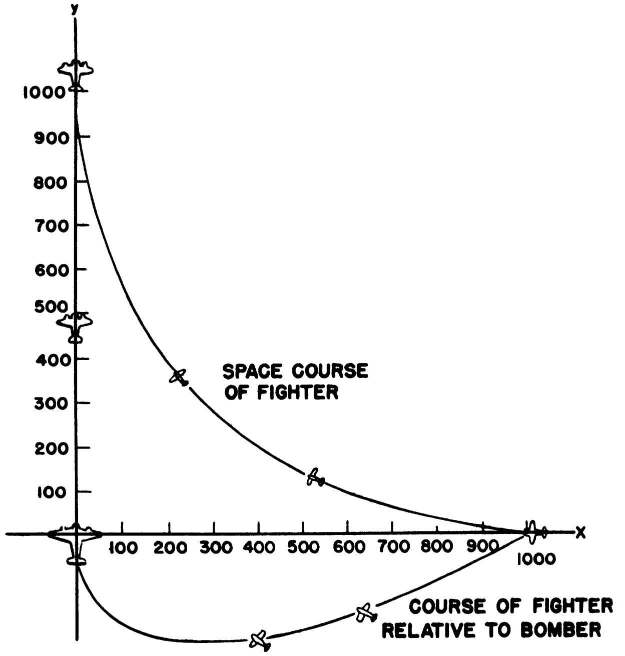

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Figure 8-20.—Air and relative courses of fighter pursuing a bomber.

projectile to travel along a parabolic trajectory. To compensate for its effect, the point of aim must be slightly above the target. Military rifles have this gravity compensating feature built into them in the form of an adjustable sight whereby the rear sight peephole is raised as the firing distance increases. When the target is alined with the front and rear sight, the axis of the gun barrel is inclined sufficiently above the horizontal to compensate for the effect of gravity.

The effect of wind on the projectile is apparent, especially when firing at a distant target, but counteracting it becomes even more complicated when one realizes that the projectile travels at a continuously decreasing velocity, due to air resistance. Obviously, the slower a projectile travels, the greater will be the effect of the wind in deflecting it from its course. Nevertheless, in the stationary firing problem, the amount of deflection produced by the wind can be determined after firing a few rounds by observing how far from the bull's-eye the projectiles tend to hit. Aiming the rifle, this amount of deflection in an equal and opposite direction from the bull's-eye results in compensating for the effect of wind.

The problem in the stationary gun and stationary target situation is very simple, and the angle at which one must aim the gun in order to hit the target is easily determined.

In the case of a stationary gun platform and moving target, the situation becomes more complicated. In addition to the effects of wind and gravity, one must foretell where the target will be when the projectile arrives to hit it—the future target position.

Here, as in duck shooting, it is necessary to "lead" the target. The aim must be ahead of the duck by an angle corresponding to the distance the bird is expected to fly between the instant of firing and the time it takes the shot to travel the distance between the gun and the bird. This idea may also be expressed by: "The present position data are used to estimate the future position of the target based upon the rates of change of present position data." In duck shooting, as the bird flies at a relatively slow speed compared to the speed of the shot, the determination of the necessary lead angle is not too difficult and is easily estimated after some experience.

This case is essentially the problem of antiaircraft fire, but also applies to the fighter pilot's problem of correctly aiming forward-firing guns. The basic aiming allowance here is for the target's relative motion during the projectile's time in flight (kinematic lead). Additional slight modifications of the gun bore's position must also be made to allow for gravity drop (ballistic lead).

This case is also similar to the problem of precision bombing or aircraft strafing. In these situations, negative leads are required and the problem is actually "gun platform moving and target stationary." Although similar, there is an important physical difference. In the strafing problem, the velocity of the gun platform is added to the muzzle velocity to obtain the initial velocity of the projectile. The projectile velocity is important in determining time of flight, and time of flight is one of the determining factors in establishing the point of aim. Therefore, there is a slightly different method of solution of the antiaircraft problem and the strafing problem. In the air-to-air problem the initial velocity of the projectile will be established as in the strafing problem.

In the case of air-to-air gunnery where two aircraft are traveling at near sonic speed and where their relative velocity begins to approach the order of the velocity of the projectiles themselves, the problem becomes much more difficult. The necessary lead angle can no longer be mentally estimated as in the case of the duck hunter, but must be continuously and accurately computed.

While this is the most complex of three general cases, it is very similar to the preceding case of gun stationary and target moving. This case is generally solved by the angular rate of travel prediction for high speed; and for lower speed involving surface ships and submarines, linear speed prediction is utilized. In aviation fire control, the angular rate of travel prediction is the method used.

AIR-TO-AIR LEAD ANGLE PREDICTIONS

By use of the concept of relative motion, and by considering the gun stationary and the target moving about it, the air-to-air problem can be resolved to the stationary gun platform and moving target case. Using the angular rate prediction method, two lead angles are material in considering the problem of a projectile leaving a moving fighter aircraft and striking a moving target. These are the lead angles necessary to compensate for the effects of the relative motion between the aircraft gun and the target (kinematic), and to compensate for the ballistic effects on the projectile during its flight.

While there are many factors that go into its determination, the lead angle necessary at any instant of time may essentially be considered equal to the product of the angular velocity of the target with respect to the firing aircraft and the time of flight of the projectile. A discussion of the main factors and their effects contributing to this determination of the lead angle follows.

Range

Range may be divided into two categories—present range (r) and future range (r_f). As pointed out in the previous section, present range may be determined optically or by radar. Future range is the distance from the weapon at the time of firing to the point of impact of the projectile. Future range is one of the factors that must be computed in the solution of the fire control problem.

Time of Flight

Time of flight (t_f) is the time taken for the projectile to cover the range from the firing point to the future position. If the present range is the target's position at the time of firing, then the time of flight is the time for the projectile to travel the distance of the future range. But, the computation of future range is dependent upon a knowledge of the time of flight. Hence, it is seen that time of flight and future range are interdependent on one another. The future angular position of the target is also dependent on the time it takes for the projectile to reach the target.

If the projectile were fired at a target in a perfect vacuum, and if the projectile were not subject to deflection by ballistics factors, it would move along a straight line at a constant velocity. For such a hypothetical situation

$$\text{Time of flight } (t_f) = \frac{\text{Range}}{\text{Muzzle velocity}} = \frac{r_f}{V_o}$$

In practice, however, the influence of gravity causes the projectile to move along a parabolic trajectory and the actual distance it travels must of necessity be greater than the straight-line distance r_f. Since the projectile is traveling through air, it is decelerated by the air resistance. The amount of deceleration is determined by the air density and size and shape or contour of the projectile. Another factor affecting time of flight is the true airspeed of the aircraft which must effectively be added to the gun's muzzle velocity to determine the deceleration caused by air resistance. From these factors the average velocity of the projectile, referring to the straight-line distance r_f, must be computed to obtain time of flight. In practice the empirical equation for the time of flight becomes

$$\text{Time of flight} = \frac{\text{Range}}{\text{Muzzle velocity}}$$

$$+ \text{ Lost time of flight}$$

or

$$t_f = \frac{r_f}{V_o} + t_L$$

Relative Velocity of Target

The relative velocity of the target may be broken down into two components—range rate and angular rate. Range rate, as shown previously, is the rate of change of range in respect to time. If a radar is used for ranging, the range rate may readily be determined by electronic means. Because the gun platform is used as reference, the range rate will be the relative rate of change between target and gun. If the range rate is multiplied by the time of flight, the product is the total change in range by the time the projectile hits the target. Adding this product to the present range results in the future range of the target at the time when the projectile hits the target.

The angular velocity of the target with respect to the firing aircraft means the rate at which the line joining the target and the firing aircraft is turning or rotating, assuming the firing aircraft to be still. Thus, if the relative angular velocity is 5° per second at any particular instant of time and the time of flight of the projectile to the predicted target position is 1/2 second at that same instant, the necessary lead angle at that instant will be 2 1/2°.

Because of the three dimensions involved in the air-to-air fire control problem, angular velocity or angular rate is at times divided into two components. These are azimuth angular velocity and elevation angular velocity.

In the optical fire control equipment, the angular velocity of the target is determined during the tracking phase when the pilot flies a coordinated turn. In such a turn, the gyroscope of the sight unit is offset from its zero position by the aircraft's angular velocity in space. This offset is the result of the inherent rigidity of a gyroscope. There is only one gyroscope, but because of the method of sight construction the gyroscope determines both azimuth and elevation portions of angular velocity.

In the radar director system, measurement of angular velocity is accomplished by means of two rate gyroscopes located in the antenna assembly. The azimuth-rate gyro precesses whenever the azimuth component of the antenna angle changes, while the elevation-rate gyro precesses only when the elevation component of the antenna angle changes. The degree of precession of these rate gyros is proportional to the rate at which these angular components are changing.

Present Lead Angle

The present lead angle is the angle at any instant of time. The present lead angle is compared with the lead angle furnished by the computer to determine whether or not the gun platform is pointed in the right direction. The present lead angle may also consist of two components—the azimuth and elevation portions.

KINEMATICS GRAPHICALLY RESOLVED

As an example of the graphical resolution of the kinematic lead angle, first consider the case of a fighter flying a lead pursuit course towards a target when both target and attacking aircraft are in a single horizontal plane; that is, both at the same altitude. The conclusion drawn from this case is then generalized in three dimensions. A typical lead pursuit attack in a horizontal plane is illustrated in figure 8-21.

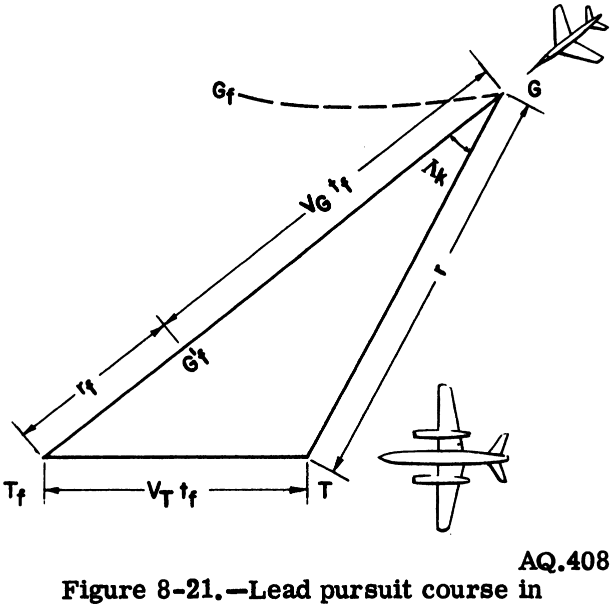

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Figure 8-21.—Lead pursuit course in horizontal plane.

Two Dimensions

In figure 8-21, the fighter is at a present position G, the target is at present position T, and the present range between the two aircraft is r. It is assumed that the fighter is on a lead pursuit curve; that is, a projectile fired at (this) present time will arrive at the future position of the target, T_f, with the target and will score a hit. The kinematic lead angle is denoted by using the Greek letter lambda (Λ_k).

As shown in figure 8-21, the fighter will be turning at the time of firing. However, such fighter motion will have no effect on the flight of the projectile. Only the direction and speed of the fighter at the time of firing affect the flight of the projectile. So far as the projectile is concerned, it is assumed that the fighter continues to fly in the same direction as at the time of firing, although in reality this is not true. The actual position of the fighter when the projectile hits the target will be G_f. For the purpose of calculation, it is assumed that the future position of the fighter is G_f' which lies on the flightpath of the projectile.

Referring once again to figure 8-21, the target flies from T to T_f while the projectile travels from G to T_f and the fighter is assumed to fly from G to G_f'. The time of flight of the projectile is denoted by t_f. (Be careful not to confuse this with T_f—target future position.) Therefore, the target flies a distance equal to its velocity multiplied by the flight time of the projectile or V_Tt_f. The fighter flies a distance equal to its velocity multiplied by the flight time of the projectile or V_Gt_f. The distance between the fighter and the target when the projectile hits the target is called the future range r_f. This is also the distance or range the projectile would attain in front of the fighter during its time of flight.

Consider the relative motion of the target in respect to the fighter. The relative course will be a straight-line course at a constant speed. The initial range is r, and t_f seconds later the range will be r_f. Figure 8-22 shows this relative course.

In figure 8-22, the relative position of the fighter remains fixed at G throughout the course. The present position of the target is T. Thus, the present distance to the target is r and is represented by the line GT. The target appears to fly in a straight line (at constant speed, V_T) towards position T_f, which is the relative position of the target t_f seconds after the present time. The relative distance it flies is V_Tt_f. The future position of the target T_f is at range r_f from the fighter which is represented by the line GT_f. Therefore, the present kinematic lead angle, Λ, is the angle between the line of sight and the line of flight of the fighter.

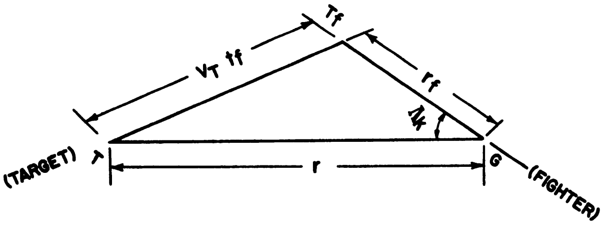

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Figure 8-22.—Relative motion of target to fighter on pursuit course.

Three-Dimensional Case

Now consider the three-dimensional case. In this case the fighter and target may be climbing or diving, but it is still assumed that the target is flying a straight line, constant speed course. The three-dimensional situation of a fighter attacking a target is shown in figure 8-23. The target flies horizontally from T to T_f (fig. 8-23) while the fighter is diving on the target. Notice that the target's course is intersected at T_f by the extension of the fighter course.

This problem differs from the preceding two-dimensional case in that the determination of the kinematic lead angle is dependent upon two factors—the azimuth component, Λ_{kA}, and the elevation component, Λ_{kE}. As in the single plane case, the lead angle is dependent upon angular velocity. When using the radar system for computing the lead, the angular velocity of the target is determined by rate gyroscopes positioned on the antenna. In the optical system, airstream direction detectors are used for measuring the angle of attack and the angle of skid. In both systems the information concerning both the elevation and azimuth angles is fed to a computer where the other factors are added. The result is computation of a correct lead angle resulting in the projectiles arriving at T_f at the same instant as the target.

The preceding discussion of the kinematic lead angles (lead angles due to the relative motion of the attacking aircraft and the target) was developed under the assumption that the flightpath of the projectile is a straight line in space. This neglects the effects of the ballistics

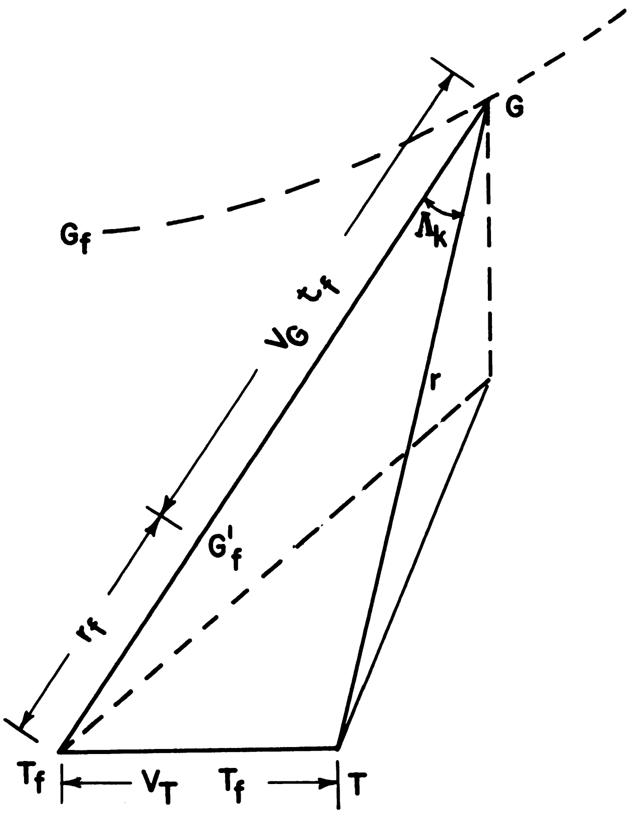

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Figure 8-23.—Three-dimensional view of pursuit course.

factors. The ballistics lead angles are generally much smaller than the kinematic lead angles, but must be taken into account.

WEAPONS SYSTEM CONCEPT

In the relatively recent past when a weapons system was mentioned, it was in reference to a fairly unsophisticated special purpose system. The components that made up the system, when installed in the aircraft, were independent of any of the other systems in the aircraft. At the time they were not very complicated, since aircraft speeds were quite low and targets were attacked at comparatively short ranges. The accuracy of the system was dependent to a great extent on the operator. This arrangement was true of nearly all of the many systems required to perform the aircraft's mission. As aircraft altitudes increased and speeds reached the supersonic regions, the ability of the attacking aircraft to perform its mission became more difficult. To engage a target at supersonic speeds was impossible when depending only on the operator for accuracy. To solve these problems automatically and accurately, the equipment became very complex.

The result of all this was that current aircraft are designed and built as a completely integrated machine. Each of the heretofore separate systems are now subsystems which are interconnected and dependent, to some extent, on each of the others. For example, the navigation system is dependent on the radar system; and the automatic flight control system is dependent on a computer, which is dependent on both the radar and navigation systems for proper operation.

The F-4B is an example of one of the first aircraft to be designed and built as a complete weapons system. Another aircraft that has since joined the fleet is the A-6, which has a completely integrated weapons system.

SUBSYSTEMS

Even though all the systems are interdependent and interconnected, much of the familiar identification nomenclature is still retained. Although reference is made to individual systems, it is becoming increasingly difficult to separate them. The AQ will normally have a primary responsibility for the aircraft's weapons system.

Fire Control System

In recent type aircraft, the fire control systems are often called intercept systems; and if they have missile capabilities, they are also referred to as missile control systems. Either is used to intercept an airborne target or attack the enemy on the surface. Many of the newer aircraft have multiple capabilities—missiles, bombs, rockets, and guns. Hence the term weapons system.

There are basically two types of intercept systems, visual and all-weather. Normally both types are provided; each type is used to best advantage by the pilot, bombardier/navigator, or other crewmember, depending on the type target being attacked. A visual attack could be made on a surface target with good results, whereas perhaps an airborne target would require the all-weather attack since long-range detection is usually required and radar is then employed to lock on and track the target.

SYSTEM COMPONENTS

The effective use of any weapon requires that a destructive device (usually containing an explosive) be delivered to a target—usually a moving target. To deliver the weapon accurately, both the velocity and location of the target must be known. Many targets now travel faster than sound, and must therefore be engaged at great distances. Against such targets, a weapon is most effective when it is used as part of a weapons system. A weapons system is the combination of a weapon (or multiple weapons) and the equipment used to bring their destructive power against an enemy.

A weapons system includes the following:

1. Units that detect, locate, and identify the target.
2. Units that direct or control the delivery unit or the weapon or both.
3. Units that deliver or initiate delivery of the weapon to the target.
4. Units that destroy the target when in contact with it or near it. These units are usually termed weapons.

Detecting Units

The first steps in using a weapons system and solving the problem are to detect, locate, and identify the target. Initial contact may be visual or it may be made by radar. It is difficult to detect a target visually at long range, or even at short range, when visibility is poor. For that reason, targets are usually detected by radar. Radar gives all three coordinates necessary to determine the position of the target. These are range, elevation, and azimuth positions.

Optical devices are used to supplement this information on occasions, such as for slow-moving targets or for short ranges. They are practically useless against missiles and most jet aircraft which usually must be engaged while they are still beyond the range of optical devices.

After the target has been detected and located it must be identified. To do this requires a device called IFF (identification, friend or foe). Radar alone cannot tell the difference between a friendly or enemy target. IFF equipment consists of two major units—the challenging unit which asks the question, friend or foe, and the transponder (responding unit) which answers the question. The challenging unit is a receiver/transmitter that sends out a pulse of radio energy toward the target. If the target is friendly, it will carry a transponder, which also consists of a receiver and a transmitter. When the receiver picks up a challenge, it causes the transmitter to send out an answering pulse or pulses, which is usually a coded message. This message is picked up by the challenging unit's receiver and displayed on the radar indicator.

Control Units

Control units in a weapons system develop, compute, relay, and introduce data into a delivery unit, weapon, or both. They direct, control, or guide the weapon to the target, and cause it to function in the desired manner. These units form the heart of the weapons system.

The devices that perform the control functions include data transmission systems that send target position information developed by the detecting units to the rest of the weapons system. Examples are synchro, resolver, and potentiometer circuits. Computer devices process the input data from the detecting units and other sources, and put out information used in aiming to cause the weapon to reach the target. Reference devices such as stable elements establish reference planes and lines of fire, lines of sight, and other references. These units are usually gyroscopically controlled.

Delivery Units

Broadly speaking, delivery units launch or project destructive units toward the target. Examples are guns, missile and rocket launchers, etc.

Destructive Units

The end purpose of the detection units, control units, and delivery units is to cause the destruction unit to intercept or pass near the target. It is then the function of the destruction unit to destroy or inflict maximum damage to the target.

CHAPTER 9

THE BOMBING PROBLEM

As with aircraft guns and rockets, whether a bomb strikes a target depends on the aircraft being in the proper position and attitude in relation to the target at the time of release. Accordingly, weapons system furnish information (visual and computed), which will assure a hit if the pilot will put his aircraft on the flight path indicated, and if the projectile is dropped or released in accordance with the predetermined ballistic formula.

Several types of bombing attacks have been developed, each with particular advantages and disadvantages, and each designed to fit certain needs. In general, determination of the required type of bombing depends on such factors as:

1. Nature of target.
2. Nature of ground and air defense.
3. Type of damage desired to the target.
4. Weather conditions over the target.
5. Distance to the target.

To meet these tactical requirements, a number of general types of bombing have been evolved for Navy use.

These methods of bombing may be divided into the following categories:

1. High level horizontal bombing (altitude 5,000 ft and above).
2. Low level horizontal bombing (low altitude).
3. Toss, loft, and over-the-shoulder bombing (low altitude).
4. Dive bombing.

Level bombing consists of the aircraft flying a straight horizontal line during its bombing run.

VACUUM TRAJECTORY

In discussing high level bombing, first consider the action of a free falling body in a vacuum. Referring to figure 9-1 suppose that the bomber travels the line from 0 to 0' with a constant speed V_g knots. Suppose also that the bomber requires t_f seconds to cover this distance, that the bomb is released at point 0, and that the bomber is H distance above the target at T. Since no air resistance is presumed to be acting, the horizontal component of the bomb's velocity is the same as the bomber's velocity at all points of its trajectory. Thus it can be seen that during its fall the bomb will remain vertically below the aircraft. The space path of the bomb is shown in the figure while its path relative to the bombardier is simply a vertical straight line.

Since the distance traveled horizontally is equal to velocity multiplied by time, the bomb's horizontal travel, or range R, is equal to $V_g t_f$. The angle formed at the time of release between the true vertical and the line of sight is called

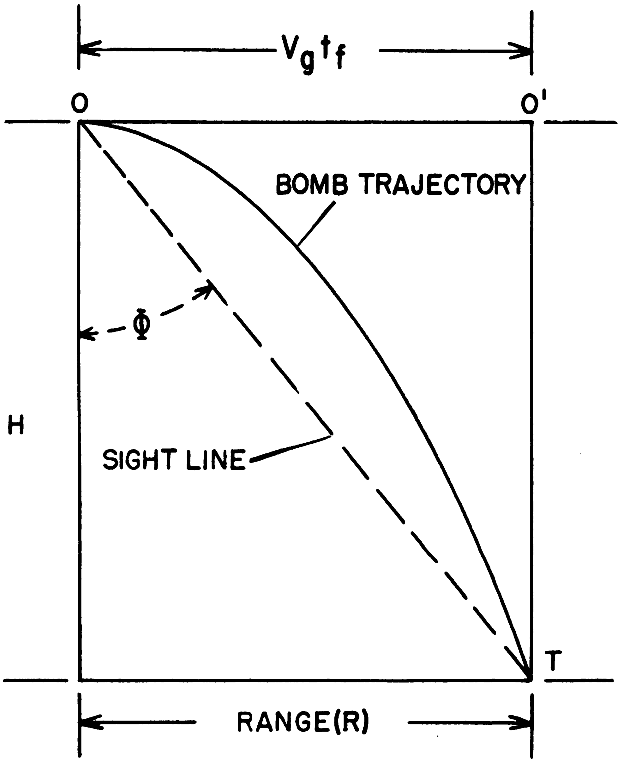

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Figure 9-1.—Bomb trajectory in a vacuum.

the range angle. The symbol for the range angle is shown as the Greek letter ϕ (phi).

To determine the range angle, three factors are required—aircraft velocity (V_g), altitude (H), and acceleration due to gravity (g). Acceleration due to gravity remains constant. This leaves two variable, H and V_g. The variables can be measured and the range angle ϕ computed. Therefore, to hit a target when flying straight and level at a predetermined altitude and speed, it is only necessary, assuming air resistance on the bomb during its fall to be negligible, to drop the bomb as soon as the target appears at the angle ϕ from the vertical.

AIR TRAJECTORY— NO WIND CONDITION

Now consider the bombing problem in air but under no wind conditions. The difference between the two situations is the effects of air resistance which has two important effects on the path of the bomb. First, it decreases the vertical velocity of the bomb, thereby increasing the time of fall. Second, it diminishes the horizontal velocity of the bomb, thus causing the bomb to trail behind the vertical line of the bomber.

The exact effect of air resistance on a particular bomb depends on the type of bomb as well as the release conditions. For example, a small, streamlined bomb is less affected by air resistance than a large, irregularly shaped bomb of equal weight. Consequently, the small bomb falls faster and its time of fall is less. The effect of air resistance on any bomb is determined by the bomb's "ballistic coefficient." The ballistic coefficient for any bomb type is obtained from tables determined from actual bomb drops. Therefore, in addition to altitude above the target and vertical velocity, the time of fall for a bomb dropped in air is dependent upon the ballistic coefficient.

The effect on range is that the bomb no longer remains beneath the aircraft while falling, and that range no longer equals time of fall (t_f) multiplied by aircraft groundspeed (V_g). This is because the air resists the horizontal motion of the bomb, causing a gradual reduction of its horizontal velocity. The effect of the increase in t_f is more than offset by the decrease in the bomb's horizontal velocity. Figure 9-2 shows the effect of air resistance on bomb trajectory, and for comparison the trajectory of an ideal bomb in a vacuum.

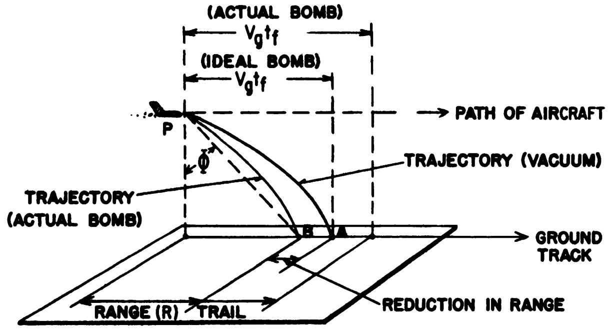

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Figure 9-2.—Effect of air resistance on bomb trajectory.

With a constant airspeed and course, the horizontal distance that the bomb has lagged behind the aircraft at the instant of impact is called trail (T'). The amount of trail is governed by the aircraft's airspeed at the time of release. In addition it is dependent upon the altitude of release and the ballistic coefficient of the bomb. Trail values for each type of bomb are determined during the calibration of the bomb at the proving ground and are set forth in tabular form, trail being given in angular measure (mils). In bombing practice the value of an angle in bombing mils may be found by dividing the distance on the ground by 1/1000 of the altitude.

Figure 9-2 shows that the range (R) of the bomb dropped in air is obtained by subtracting the linear trail value from the vacuum range. An ideal bomb dropped from point P hits the ground at impact point A. During the time of fall, the aircraft travels distance $V_g t_f$, where t_f is for the ideal bomb. Thus, at impact, the aircraft is directly over point A. An actual bomb dropped from point P hits the ground at impact point B because of air resistance. Since t_f for the actual bomb is greater than that for the ideal bomb, the aircraft travels the distance $V_g t_f$ (actual) during the time of fall. Thus, trail includes not only the reduction range, but also the travel of the aircraft during the additional time of fall.

DRIFT AND TARGET MOTION

Up to this point the discussion of the bombing problem has assumed the conditions of still air and a stationary target. Now consider the problem with the introduction of wind. Assuming a standard air structure, the wind is considered as moving horizontally only, with constant speed and direction at all points of the bomb trajectory. Thus, no vertical component of wind is considered.

As pointed out in chapter 8, the principal effects of either a headwind or a tailwind is the change made in the closing speed of the aircraft. The problem is to consider the effects of a wind other than a headwind or tailwind. This is shown in the diagram of figure 9-3.

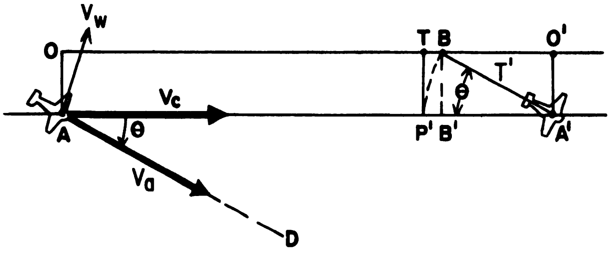

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Figure 9-3.—Drift angle and trail.

In figure 9-3 the line AD gives the direction in which the aircraft is being steered, namely the aircraft's heading. The vector V_a is the velocity of the bomber with respect to the air. The wind vector V_w, representing the velocity of the air with respect to the ground, combines with V_a to give V_c (V_g and V_c are the same when the target is stationary), the velocity of the bomber with respect to the ground. The line AA' is the line of action of vector V_c and is called the bomber's track. The angle θ (theta) formed by the heading and the track, is called the drift angle. (The Greek letter theta is used here to denote drift angle. In some bombing computers letters may be used to denote drift angle while theta denotes the angle between true north and the aircraft centerline.)

There are three important points to be noted in figure 9-3. First of all, the direction of the trail (T'). The trail always lies in a line through the forward-aft line of the aircraft and is independent of the wind. Second, it will be noted that because of this fact the bomber, to obtain a hit, must fly so that its track will pass to one side of the target by the amount P'T. (NOTE: P'T equals T' sin θ.) This quantity is called the crosstrail. Third, as figure 9-3 shows, the bomb will strike (unless a special correction is made) not at the target T but at a slight distance forward at B. To account for this, it must be remembered the trail (T') is independent of wind and therefore θ. Thus, only when θ is zero, namely for flight in still air, upwind or downwind along 00', will the bomb strike at T. Therefore, to secure a hit at T, the bomb should be released when the aircraft is the distance TB back from A' along the track. This factor is called the range component of crosstrail. It is usually very small, being obscured by other bombing errors, and for this reason is sometimes omitted from consideration.

So far, consideration has been given only to stationary targets. In order to take target motion into account target velocity must be resolved into components along and perpendicular to the aircraft's heading. Then that component of the target's motion along the aircraft's heading gives the same effect as a headwind or a tailwind depending upon whether its direction is the same or the opposite of the aircraft's direction. Similarly, the component of the target's motion across the aircraft's heading may be considered as a crosswind and absorbed in the solution for the drift angle by combining it with the wind vector. Hence the effect of target motion is merely to change the values of aircraft velocity and wind velocities (V_a and V_w) and then to regard the target stationary as before. The correct range or dropping angle ϕ is a function of the trail, altitude above the target, time of flight of the bomb, and the closing speed, V_c.

RELEASE POINT COMPUTATION

The release point problem consists of determining the course to fly and the point along that course at which the bomb must be released to hit the target. Release point computation is based on solution of the tracking and bomb ballistic problems.

Tracking establishes the position and relative motion between the aircraft and the target. Tracking data are obtained by tracking the aim point, which may be either the target or an aim point displaced from the target. A displaced aim point can only be tracked when the target is stationary, and the position of the target with respect to the aim point is known. Position data establish the initial position of the aim point with respect to the aircraft, and the rates continuously establish the change in position of the aircraft relative to the aim point.

As noted before, the correct range or dropping angle ϕ is a function of the trail, altitude above the target, time of flight of the bomb, and the closing speed. Previous to this, there is the problem of establishing the proper track parallel to a collision course with the target, and at a distance equal to the crosstrail.

A bombing computer for determining ϕ will then have as inputs T', H, t_f, and V_c. The trail (T') is obtained from trail tables, wherein it is given as a function of altitude, airspeed, and bomb ballistic coefficient, and can thus be set in by the bombardier. The altitude input is available from an altimeter while time of flight is tabulated as a function of altitude. Closing speed is obtained by tracking the target with the use of optical devices, a television camera, or radar keeping the crosshairs or range and azimuth cursors continuously on the target. This method of computing the release point is similar to the range angle method used when tracking with a bomb sight.

Modern bombing equipment provides stabilization of the sighting unit (radar antenna, TV camera, etc.) so that references are available from which to measure the range and drift angles. Chapters 7 and 12 of this manual describe stabilization.

HIGH LEVEL BOMBING

High level bombing altitudes are considered to extend from approximately 5,000 feet to the ceiling of the aircraft. The greater the altitude the safer it is from conventional ground fire; but the more difficult the problem and the more precise must be the information used to solve the problem. Many factors must be taken into consideration, some of which are discussed in chapter 8 of this manual.

LOW LEVEL BOMBING

Low level bombing is usually considered to be from 5,000 feet and below. At such altitudes many complications present themselves that are of lesser consequence in high level bombing. There are also factors encountered in low level bombing that are not a part of the high level bombing problem.

At low altitudes the attacking aircraft may be subjected to severe conventional ground fire. This problem has been partially solved by flying very low to avoid detection; however, extremely low altitude flight presents another very serious problem. This is the problem of avoiding the terrain, which includes mountains in many areas or other obstructions. The solution was the development of a special terrain clearance radar.

The increasing speeds of modern aircraft have made it impossible to bomb at low altitudes with accuracy when depending on bombsights and the pilot's judgment. Thus, automatic bomb release systems have been developed and are used in modern aircraft. To point out the need for automatic release equipment, two methods previously used in low level bombing are discussed briefly.

A bombsight which will operate effectively at altitudes below 5,000 feet, requires extreme accuracy in measurement of the input variables when the range angle method is used for determination of the bomb release point. This is especially pronounced when the altitude falls below 1,000 feet, as it does in the case of depth bombing of submarines from low flying aircraft. At such low altitudes the trail value is negligible by comparison to other factors. Therefore, unless the altitude and closing speed can be held very close to the preassigned values, errors in these quantities will produce large range errors. To overcome these difficulties, the angular rate method was used to determine bomb release.

During the early stages of a low level approach, when the target is at a considerable distance from the aircraft, the angle of depression changes very slowly so that the angular velocity of the target at the observer's eye is low. (See fig. 9-4.) As the aircraft nears the target, the angular velocity increases, finally becoming a maximum as the aircraft passes vertically over the target.

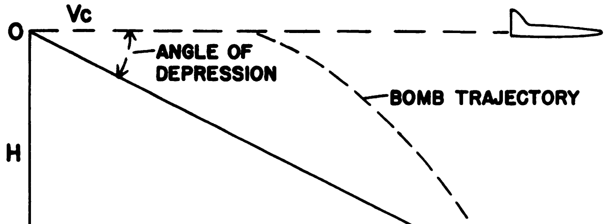

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Figure 9-4.—Low level bombing.

At some point during this bombing run, the target was in an appropriate position for a bomb to be released. At that point it had an angular velocity that could be calculated in terms of the height and groundspeed of the aircraft. If this calculated angular velocity is set up on a bombsight in such a manner that the exact moment when the target had an equal angular velocity, then there would be an indication of the exact instant when the bomb should be released. The solution of the low level bomb attack as just described, would be impossible with today's high speed aircraft because of the human error factor.

DIVE BOMBING

Dive bombing is accomplished by flying along a dive bomb path as illustrated in figure 9-5. This path provides the proper aiming allowance at the release point to obtain a hit. By following a path as shown, the aircraft is directed at point A beyond the target T, so that when the bomb is released at point R it will not fall short due to gravity. Hence at release, the line of sight to the target and line of flight are at an angle to each other.

In the development of dive bombing, as the altitude for beginning the pullout increased, the need for equipment to indicate the correct release point increased. The big problem in dive bombing has always been to try to determine the proper point to aim the aircraft. For any given aircraft speed, aircraft load, and dive angle, the amount of offset that must be allowed above or below the boresight line of the aircraft, so that the aircraft will fly a straight path to the target, can readily be determined. However, the bomb, when released, will always fall short by an amount which is mathematically a function of height and ballistics of the bomb. Accordingly, the problem has been solved by diving the aircraft at a constant speed with a known load and dive angle, while aiming the aircraft at the target in accordance to offset corrections determined by the bomb director.

A sight was constructed to operate on the angular rate principle, but after numerous flight tests, was finally rejected for the following reasons. First, it was found too difficult for the pilot to maneuver his aircraft in the diving attitude so as to achieve synchronization. Actually, the pilot had to fly a curved path through space and at the same time try to recognize a condition of no drift between the crosshairs and the target. Second, when once in a dive, the pilot found it almost impossible to make a deflection drift correction since there is no way to make an aircraft move sideways in space. The fact that range and deflection drift change continuously, creates a problem virtually impossible for the dive bombing pilot to solve.

The difficulties just mentioned have been reduced by new equipment, but cannot be avoided altogether, since they are inherent in the dive bombing method. The method of toss bombing, considered in the next section, eliminates these difficulties for the pilot by permitting him to dive straight at the target.

TOSS BOMBING

In toss bombing, the aircraft is flown initially along a collision course, a straight-line path containing the target. If the bomb was released en route, gravity would cause it to fall short. To overcome this effect, the pilot pulls out of his straight-line dive and releases the bomb at a precalculated point along the pullout curve.

Toss bombing is accomplished by flying along a toss bomb path as illustrated in figure 9-6. This attack varies from dive bombing in that the flight path is directed at the target for a short period, at the end of which a pullup is executed (point B). The bomb is released at a suitable point R along the pullup curve.

To relieve the pilot of the responsibility of computing and trying to maintain all the necessary conditions, several bomb directors have been devised to aid the pilot in solving the bombing problem. In toss bombing, release does not occur until after pullout has imparted to the missile a velocity whose horizontal

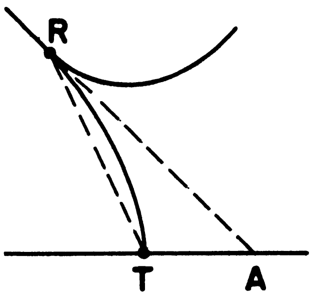

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Figure 9-5.—Dive bombing.

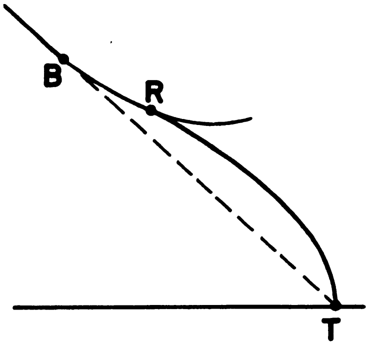

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Figure 9-6.—Toss bombing.

component is the correct one for the trajectory of the bomb. The angle of attack and the dive angle are measured by a gyro which establishes a line reference. Thus, the pilot has only to control speed, or average speed, and aim the aircraft for the proper allowance.

LOFT BOMBING

Loft bombing furnishes the best solution to the problem of dropping powerful bombs from a low altitude without endangering the dropping aircraft. Dive, toss, and glide bombing methods are inadequate for such low altitude bombing because they place the aircraft in a position where it is vulnerable both to the bomb blast and the antiaircraft fire in the target area.

The loft bombing attack uses the high speed of modern fighters and light bombers to throw the bomb from the release point to the target, giving the aircraft an opportunity to escape. The entire loft bombing attack is made at a low altitude, making it possible to evade radar tracking, and the aircraft can be well clear of the blast when the bomb goes off. If there is a low overcast, the aircraft can come in just under it and pull up into the clouds. The necessary computations and release signals for this attack are developed in the loft bombing equipment.

The attack path, as shown in figure 9-7, requires that the aircraft pass over a landmark (identification point) in direct line to the target at a specified altitude. After the elapse of a preset time interval, a pullup is executed at point B. The pullup point is determined by the characteristics of the aircraft and must be sufficient so that the aircraft will pass through the release point R at the desired climb angle.

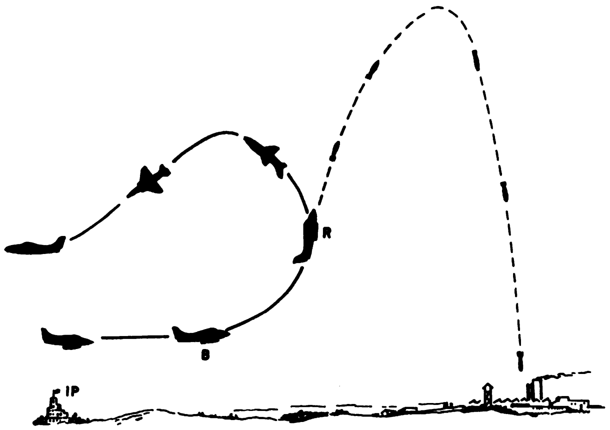

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Figure 9-7.—Loft bombing.

In contrast to the toss bombing maneuver, in which no preflight planning is necessary except that required for determining line of flight with respect to the armament datum line, the loft bomb attack must be planned in detail and executed according to plan.

The release point (fig. 9-7) is determined by the speed of the aircraft at the instant of release and the desired horizontal range and altitude. In the attack the pilot flies so that he will pass over the identification point (landmark) in a direct line to the target. The approach is made in level flight at a prescribed altitude. At the instant he passes the landmark, the pilot presses a switch and keeps it depressed until actual bomb release occurs.

At the end of the preset time interval, or in other words, at the pullup point, the pilot's indicator presents the signal to indicate that he should commence pullup. The pullup should be at a constant number of g's. Bomb release occurs automatically when the product of pullup acceleration, pullup time and release angle reaches a preset value. After the bomb has been released the pilot may make any desired maneuver to leave the target area.

OVER-THE-SHOULDER BOMBING

In the event that the identification point is missed or cannot be used, or should the type mission require a different type attack, the attack known as over-the-shoulder may be executed. The maneuvers necessary for the pilot to perform for this type delivery is illustrated in figure 9-8. The approach to the target and the aircraft maneuvers are identical, as shown in the figure. The only difference is that in over-the-shoulder bombing the target and the identification point are the same. This means that the pilot will depress the bomb release switch when directly over the target, and the bomb is automatically released at a predetermined angle. As can be seen, the angle of release is greater than that used in loft bombing.

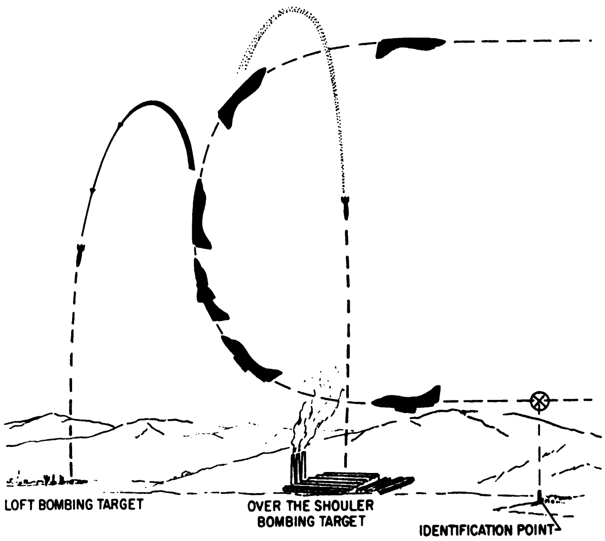

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Figure 9-8.—Over-the-shoulder bombing.

CHAPTER 10

INTRODUCTION TO RADAR

The term RADAR was coined by the United States Navy in 1941 by combining the first letters of the words RAdio Detection And Ranging. The word is now commonly applied to electronic equipment used to detect the presence of objects and to determine their direction, altitude, and range by means of reflected radio waves.

RADAR DEVELOPMENT

The development of radar into the highly complex systems, as it is known today, is the accumulation of many developments and refinements contributed by many men of many nations. While the development of radar as an operating system goes back only to 1928, the general principles have been known and used for a long time.

Many discoveries were necessary before a useful system was realized. Some of these are listed as follows:

1. The reflection of radio waves by certain types of objects.
2. The formation of these waves into a beam.
3. The measuring of distance by timing the travel of a radio wave.
4. The detection of the reflected wave.
5. The pulse method of measuring distance.

The final step was the combining of these discoveries into an operating device. Not until the last step was radar invented in the strictest meaning of the word; but since this last step depended upon all the preceding steps, credit must be given to all who participated in the invention.

RADAR IN WORLD WAR II

World War II played a large part in the development of radar in that it speeded up the process by forcing its development as an operating device. Since the nation's security was at stake, very little information concerning radar was made known. The public was aware that there was a marvelous new weapon that had something to do with radio, but beyond that they knew little. This secrecy caused much widespread speculation concerning this new "secret weapon." Many of the tales told were strictly the figment of the imagination, but radar did cause many changes in the methods of waging war. In World War II many naval battles were fought at night. Prior to this, no great naval battles were waged in the darkness, since you could not shoot at an enemy you could not see. In a typical incident of World War II, a new American warship was cruising the South Pacific searching for the enemy. Aboard the American vessel, radar, like an invisible searchlight, probed the darkness and discovered the presence of an enemy vessel more than 8 miles away. The big ship lifted its radar synchronized guns and the second salvo, despite darkness and extreme range, landed squarely on the target. This incident would not seem unusual today, but imagine how amazing it was then—for the first time to have destroyed the enemy without ever having seen him. Such events became common even in the early part of the war.

AIRBORNE EQUIPMENT

The early radar systems were bulky and also weighed considerably more than could be accommodated by the aircraft of the time, but it did not take long to reduce the size and weight to the point where the radar system could be installed in an aircraft. Again the pressing need of superior weapons with which to wage war accelerated the development of airborne weapons systems. The early systems installed in aircraft were not nearly as sophisticated as those of the modern day weapon systems, but the radar was a powerful aid to the aircraft. The aircraft also proved to be an aid to the radar since it supplied an elevated platform, thereby extending the effective range at which objects could be detected. The application of radar to airborne operations has been most successful, and airborne radar is an indispensable part of the Navy's fighting team.

Airborne radar is designed especially to meet the strict space and weight limitations that are necessary for all airborne equipments. Even so, airborne radar sets develop the same peak power as shipborne and shore-based sets are capable of producing.

As with ships, there are many models and types of airborne radar sets to serve many different purposes. Some of the sets are mounted in hugh blisters that form part of the fuselage; while others are mounted in the nose of the aircraft.

In fighter aircraft, the primary mission of radar is to aid in the search, interception, and destruction of enemy aircraft. This requires that the radar have a tracking feature. There are many other purposes. The following are some of the general classifications of airborne radar; search, intercept and missile control, bombing, navigation, and airborne early warning.

CHARACTERISTICS OF RADAR

RANGE

Radar measurement of range or distance is possible because of the fact that radiated RF energy travels through space in a straight line at a constant velocity. The straight path and constant speed are changed slightly when the RF waves enter the atmosphere and will vary with atmospheric and weather conditions. (This is discussed later in this chapter.)

Velocity

RF energy travels at the speed of light, about 186,000 statute miles (162,000 nautical miles) per second. This is 300,000,000 meters per second in the metric system. Radar timing is usually expressed in microseconds, and the velocity of radar waves is often given as 328 yards or 984 feet per microsecond.

One nautical mile is equal to approximately 6,080 feet. This means that it takes RF energy approximately 6.18 microseconds to travel 1 nautical mile.

Range Measurement

The pulse type radar set determines range by measuring the elapsed time during which the emitted pulse travels to the target and returns. Since two-way travel is involved, a total time of 12.36 microseconds per nautical mile will elapse between the start of the pulse from the antenna and its return from a target. The range in nautical miles of any object can be found by measuring the time elapsing during a round trip of the radar pulse (in microseconds) and dividing this quantity by 12.36. In equation form, this is:

$$\text{Range} = \frac{\text{elapsed time}}{12.36}$$

MINIMUM RANGE.—The minimum range capability of a pulse radar is determined by the time of the transmitter pulse, or pulse width (PW), plus the recovery time of the duplexer and the receiver. (For purposes of this explanation, recovery time may be considered as the time required for the receiver to become operative after the transmitter has fired.)

The minimum range in yards, at which a target can be detected, is equal to the PW plus the recovery time, divided by 2 and multiplied by 328 yards (328 yd/ sec.). Stated in formula:

$$\text{Minimum range} = \frac{\text{PW} + \text{recovery time}}{2} \times 328 \text{ yd}$$

$$= (\text{PW} + \text{recovery time}) \times 164 \text{yd}$$

Targets closer than this range are not seen because the receiver is inoperative for the period of time necessary for a signal to travel this distance.

An increase in recovery time (bad TR tube in the duplexer) not only increases the minimum range, but also decreases the receiver sensitivity.

MAXIMUM RANGE.—The higher the frequency of a radar wave, the greater the attenuation (decrease in signal strength) due to weather effect. Gases and water vapor that make up the atmosphere absorb energy from the radiated pulse. Frequencies below 3,000 MHz are not appreciably attenuated under normal conditions, while frequencies above 10,000 MHz are highly attenuated. Attenuation of the transmitted pulse results in a decrease in the ability of the radar to produce usable echoes at long ranges. A usable echo may be defined roughly as the smallest signal which a receiver-indicator system is able to detect, amplify, and present so that the observer can visually distinguish it from the noise signals on the CRT.

At lower frequencies, higher transmitter power can be developed more easily. Also, there is greater refraction and diffraction (bending of the waves). Lower radar frequencies are therefore superior for extremely long-range search radar. The effect of atmospheric conditions on radar signals is discussed in more detail later in this chapter.

The maximum range of any pulse radar depends upon transmitted power, pulse repetition frequency, and receiver sensitivity. The peak power of the transmitted pulse determines the maximum range that the pulse can travel to a target and return in usable echo strength. Sufficient time must be allowed between transmitted pulses for an echo to return from a target located at the maximum range (established by design) of the system.

The maximum range is sometimes extended and vertical coverage reduced by the trapping of the radar beam in a DUCT. A duct is created by abnormal weather conditions; further coverage on ducts is given later in this chapter.

AZIMUTH

The azimuth (bearing) of a target is its clockwise angular displacement in the horizontal plane with respect to true north as distinguished from magnetic north. This angle may be measured with respect to the heading of an aircraft containing the radar set; in this case, it is called relative bearing. The angle may be measured from true north, giving true bearing, if the installation contains azimuth stabilization equipment. The angle is measured by utilizing the directional characteristics of an unidirectional antenna, and determining the position of the antenna when the strongest echo is received from the target.

Radar antennas are constructed of radiating elements and reflectors, and some types use a director element to produce a narrow beam of energy in one direction. The pattern produced in this manner permits the beaming of maximum energy in a desired direction. The transmitting pattern of an antenna system is also its receiving pattern. An antenna can therefore be used to transmit energy, to receive echoes (reflected energy), or both.

RESOLUTION

The range resolution of a pulse radar is the minimum resolvable separation in range of two targets of the same bearing. Range resolution is a function of the width of the transmitted pulse, the type and size of the targets, and the characteristics of the receiver and indicator. With a well-designed radar, sharply defined targets on the same bearing should be resolved if their ranges differ by the distance the pulse travels in one-half of the time of the pulse width (164 yards per microsecond of PW). If a radar set has a pulse width of 5 microseconds, the targets would have to be separated by more than 820 yards before they would appear as two pips on the scope.

The azimuth resolution is the ability to separate targets at the same range but on different bearings, and is a function of the antenna beam width and the range of the targets. Antenna beam width may be defined as the angular distance between the half-power points of an antenna's radiation pattern. (Half-power points are those points at which the transmitted power is one-half the maximum value of energy that is radiated along the lobe center.) Two targets at the same range, in order to be resolved as being two targets instead of one, must be separated by at least one beam width.

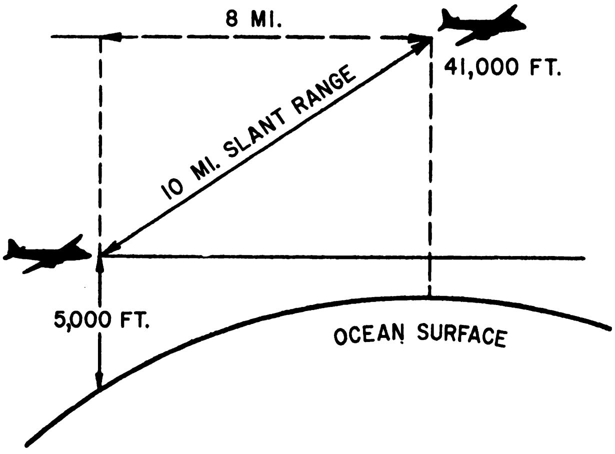
Strong multiple targets appearing as one target can often be resolved in azimuth and bearing by reducing the gain of the receiver until only the strongest portions of the echoes appear on the CRT.

ACCURACY

The accuracy of a radar is a measure of its ability to determine the correct range and bearing of a target. The degree of accuracy in azimuth is determined by the effective beam width and is improved as the beam width is narrowed. On a PPI scope the echo begins to appear when energy in the edge of the beam first strikes the target. The echo is strongest as the axis of the beam crosses the target, but the echo continues to appear on the scope as long as any part of the beam strikes the target. The target appears wider on the PPI than it actually is, and the relative accuracy of the presentation depends in a large measure on the width of the radar beam and range to the target.

The true range of a target is the actual distance between the target and the radar set (fig. 10-1). In airborne radar, the true range is often called SLANT RANGE. The term slant range is used to indicate that the range measurement includes the effect of difference in altitude.

The horizontal range of a target is a straight line distance (fig. 10-1) along an imaginary arc parallel to the earth's surface. This concept is



AT.338

Figure 10-1.—Slant range versus horizontal range.

important to the radar observer because an airborne target, or the observer's aircraft, need only to travel the distance represented by its horizontal range to reach a position directly over its target. For example, an aircraft at a slant or true range of 10 miles, and at an altitude of 36,000 feet above the radar observer's aircraft, possesses a horizontal range of only 8 miles.

The timing sequence of a radar range indicating device starts at the same instant that the transmitter starts operation. Therefore, with airborne surface-search radar, the first targets seen are those directly beneath the aircraft. However, on the PPI scope, there is a hole in the middle of the picture (fig. 10-2), with a minimum radius corresponding to the altitude of the aircraft. In some systems the radius of the altitude ring will vary as the lower limit of the vertical radiation pattern is increased by raising the tilt of the radar antenna. Objects which are actually directly beneath the aircraft appear on the scope at a distance equal to the distance between the aircraft and ground. For greater accuracy of surface ranges, the relationship between the range of the target and the range of the altitude ring must be considered.

FACTORS AFFECTING RADAR

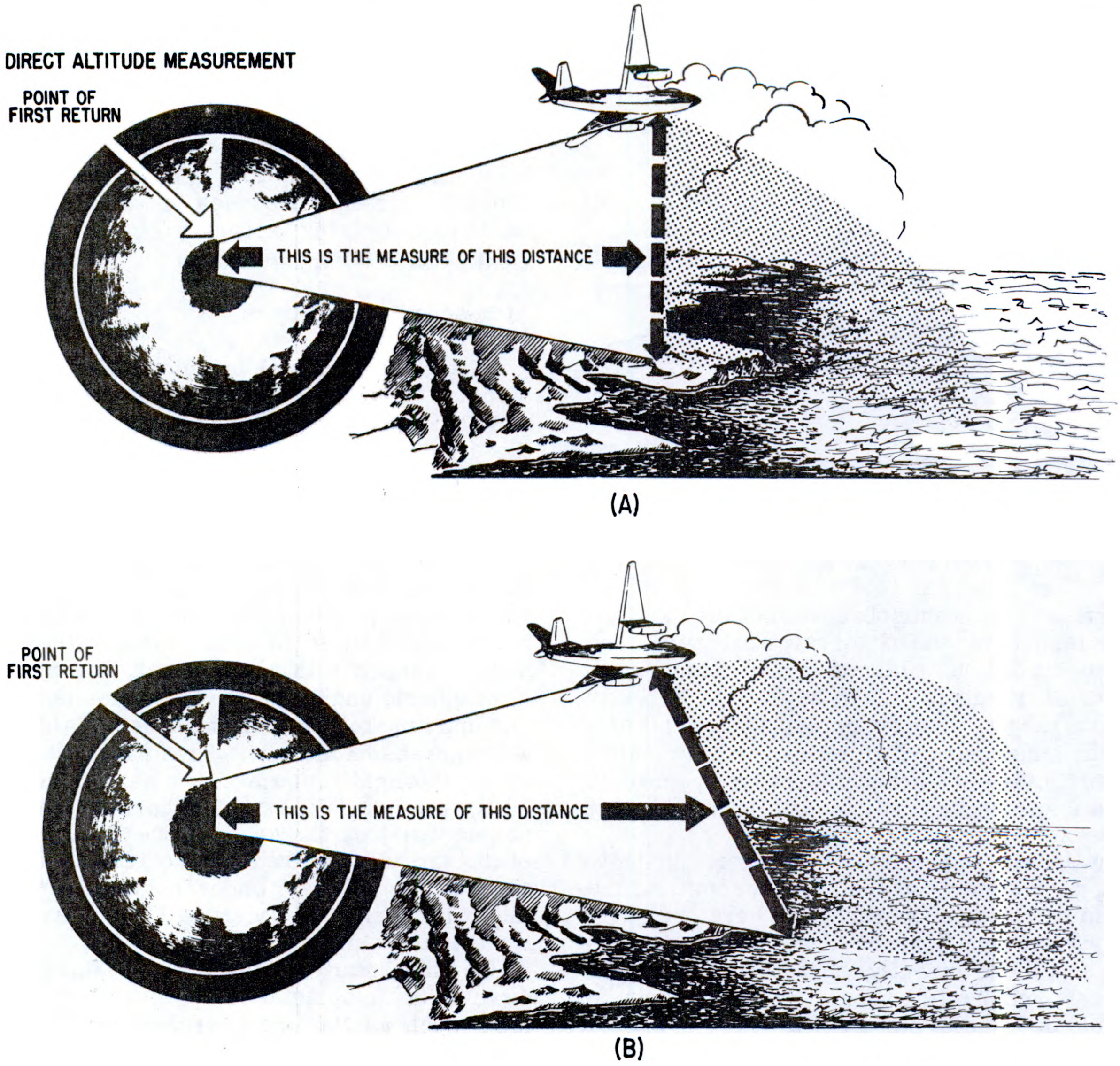
There are many factors, or elements (including atmospheric conditions), that affect radar performance. One of the principal factors is maintenance. The ability to keep the equipment operating at peak efficiency will influence the overall capabilities and limitations of the radar.

Another important factor is the radar operator's knowledge of the equipment. He must know the maximum and minimum ranges at which he can expect to pick up various targets, range and bearing accuracy of the gear, and range and bearing resolution.

Atmospheric Conditions

The paths followed by microwave and VHF signals, whether direct or reflected, usually are slightly curved. The signals travel through the atmosphere at speeds that depend on temperature, atmospheric pressure, and the amount of water vapor present in the atmosphere. Generally, the higher the temperature the faster the signal; the lower the atmospheric pressure, the faster the signal; and the less the amount of water vapor present, the faster the signal. The net result of these influences is that the signal speed changes with altitude and, under normal atmospheric conditions, the variation is a small and uniform increase in the speed of the signal with increasing altitude. This causes all paths to curve slightly downward, as shown in figure 10-3, extending the radar horizon beyond a tangent to the earth. (See fig. 10-4.) The amount of the extension of the radar horizon varies with weather conditions. Under normal conditions, the radar horizon is extended 1.25 times the optical line of sight.

To understand the reason for this curving downward, imagine a surface called a wave front such as the one represented by line AB (fig. 10-3), where A is higher in altitude than B. A wave front is a surface, not necessarily flat, chosen in such a way that the phase of the signal is the same at all points on the surface. The signal always travels in a direction perpendicular to the wave front. Now, as wave front AB moves with the signal, it reaches position A'B' after a short time interval. The speed at A and A' is faster than the speed at B and B', since A and A' are at a greater altitude. Therefore, in a given time, the upper part of the wave front moves farther than the lower part, and the wave front tips slightly forward as it moves along. Since the path followed by the signal is always perpendicular to the wave front, it curves slightly downward as the wave front tips.


DIRECT ALTITUDE MEASUREMENT
POINT OF FIRST RETURN
THIS IS THE MEASURE OF THIS DISTANCE
(A)
POINT OF FIRST RETURN
THIS IS THE MEASURE OF THIS DISTANCE
(B)

AT.339

Figure 10-2.—Effect of altitude on radar. (A) Radar tilted down; (B) radar with zero tilt.

The bending of radio or radar waves due to a change in the density of the medium through which they are passing is termed refraction. The measure of the bending that occurs is indicated by the difference in index of refraction from one substance to another. The density of the atmosphere changes at a gradual and continuous rate; therefore, the index of refraction changes gradually with increased height.

The temperature and the moisture content of the atmosphere normally decrease with height above the surface of the earth. Under certain conditions, the temperature may first increase with height and then begin to decrease. Such a situation is called temperature inversion. More important, the moisture content may decrease more rapidly with height just above the sea. This effect is called moisture lapse.

Either temperature inversion or moisture lapse, alone or in combination, may produce a great change in the index of refraction of the lowest few hundred feet of the atmosphere, resulting in greater bending of the radar waves. This may greatly extend or reduce the radar

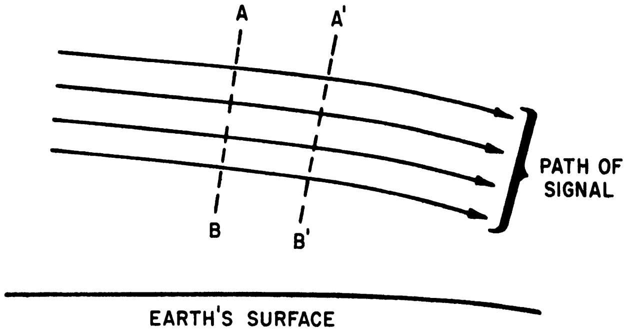


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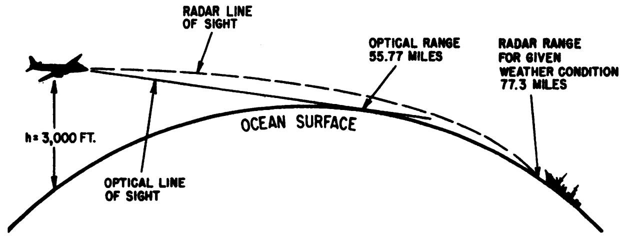
Figure 10-3.—Microwave path.


RADAR LINE OF SIGHT
OPTICAL RANGE 55.77 MILES
RADAR RANGE FOR GIVEN WEATHER CONDITION 77.3 MILES
h = 3,000 FT.
OCEAN SURFACE
OPTICAL LINE OF SIGHT

AT.341

Figure 10-4.—Extension of radar horizon.

horizon, depending on the direction in which the radar waves are bent. The height of the radar antenna with respect to the DUCT formed by this strange occurrence is of much importance.

Although duct conditions can happen any place in the world, the climate and weather in some areas make their occurrence more likely. In some parts of the world, particularly those having a monsoonal climate, variation in the degree of duct formation is mainly seasonal, and great changes from day to day may not take place. In other parts of the world, especially those in which low barometric pressure areas recur often, the extent of nonstandard propagation conditions varies considerably from day to day, even during the season when they are most common.

Sometimes, for various reasons in different areas, some upper level air becomes heated and often partially dried out. This effect is associated with clear weather rather than with storms. The temperature inversion and a layer of very dry air, which spreads out horizontally, create conditions favorable to the formation of a sky duct. The top of a duct can often be recognized by a thin layer of haze. The haze is a result of the moisture in the warm air condensing as the air starts to get colder.

MODULATION AND DEMODULATION

The word modulate, means to change, vary, or alter. At first thought, perhaps, the word modulation brings to mind the process by which radio transmissions are modulated or altered. This is natural since it is probably the best known example. There are very few people who are not familiar with the Am-FM radio.

The word demodulate, of course, is the reverse process of modulate. To demodulate is to recover the signal used in the modulation process.

MODULATION

In radio transmission, the steady RF voltage wave generated by the transmitter cannot produce an intelligible signal at the receiver. The transmitted RF wave merely carries the intelligence to the receiver. The signal which is desired to be transmitted is impressed upon the carrier at the transmitter, thereby modulating the transmission in accordance with the signal voltage.

Various methods are used to accomplish the modulation process. Sometimes the amplitude of the carrier is varied, producing amplitude modulation. Other times the frequency of the carrier is altered, the result then is frequency modulation. The phase of the carrier can also be changed, resulting in a phase-modulated carrier.

Although the modulation of transmitted radiofrequency waves is probably the most well known, there are other applications of modulation that perhaps are not so well known, or at least not recognized as a modulation process. Some of these are briefly described in the following paragraphs.

Velocity Modulation

An example of velocity modulation is the operation of the klystron which is used as the local oscillator in many radar systems. This process results in the bunching of the electrons in the electron stream emitted by the cathode. These bunches are formed by increasing the velocity of some of the electrons and decreasing the velocity of others. The operation of the klystron is described in chapter 11 of this manual.

Spin Modulation

A type of modulation which is referred to as spin modulation is actually an application of amplitude modulation. An example of this process was discussed in chapter 6 of this manual when describing the antenna positioning system. In this particular application, an error signal was developed which varied at antenna nutation frequency or the frequency of the antenna spin generator.

Intensity Modulation

A good example of the process of intensity modulation is the method used in controlling the intensity of the electron beam in a cathode-ray tube, such as in an oscilloscope. By increasing or decreasing the number of electrons allowed to strike the screen of the cathode-ray tube, the intensity of the trace can be varied.

DEMODULATION

After the process of modulation has been accomplished and the carrier with its signal has arrived at the destination, it is necessary, in most cases, to separate the carrier from the intelligence. The carrier is discarded upon recovery of the signal which was riding upon it. This process is known as demodulation or detection. Several methods of detection are described in chapter 11 of this manual.

FREQUENCY CONVERSION (HETERODYNING)

As previously mentioned, the generation and transmission of high frequency radio waves, such as used in radar, are complicated because of the physical construction of the tubes required. These high frequencies also cause difficulty in the receiver. In fact, the frequencies used in most radar systems would be extremely difficult, if not impossible, to amplify. For this reason, a special process is required in order to produce a frequency that the receiver can handle. This process is called frequency conversion or heterodyning.

In converting the carrier frequency into a frequency the receiver can handle, a special mixing process is used and the resulting frequency is called an intermediate frequency. To produce this intermediate frequency, a second signal frequency is generated and mixed with the carrier. In radar, the second frequency is supplied by the klystron local oscillator. In the mixing process, the following four frequencies are produced: the sum of the two frequencies, the difference of the two frequencies, and the two originals. Of course the difference frequency is the wanted intermediate frequency. If the two frequencies to be mixed are nearly the same, the difference frequency will be low, as compared with the two originals, and will be much easier to amplify. Treatment of this intermediate frequency signal is discussed further in chapter 11 of this manual.

SYSTEM CONSTANTS

Although all radars operate on the same basic principles, each varies according to its function. Associated with any radar are certain constants. These constants are chosen for a particular radar system, depending on its tactical use, the accuracy required, the range to be covered, the physical size, and the problem of generating and receiving the signal.

CARRIER FREQUENCY

The carrier frequency is the frequency at which the radio energy is generated. The principal factors influencing the selection of the carrier frequency are the desired directivity of the radiated beam, the desired physical size of the antenna, and the generation and reception of RF energy.

To permit the determination of direction and to concentrate the transmitted energy so that a greater amount of it is useful, the antenna should be highly directive. The higher the carrier frequency, the shorter the wavelength, and hence the smaller the antenna system for a given sharpness of pattern, since the individual radiating element is normally a half-wave in length. For example, the carrier frequency for a radar set intended for airborne use would have to be fairly high (on the order of 10,000 MHz usually) so that a small reflector may be used. Some heavy ground radar sets use frequencies so low that they must have antenna reflectors more than 100 feet long to attain the desired directivity.

The range of frequencies designated for radar operation is divided into bands, each designated by a letter. Each band is centered on a certain frequency and wavelength. Table 10-1 lists the center frequency and wavelength for each band.

Table 10-1.—Wavelength and frequency.

Band	Frequency (megahertz)	Wavelength (meters/centimeters)
P	150 MHz	2 m
L	1,000 MHz	30 cm
S	3,000 MHz	10 cm
X	10,000 MHz	3 cm
K	30,000 MHz	1 cm

Radar sets operating in the P and L bands are known as ultrahigh frequency (UHF) radar. Those operating in the S, X, and K bands are called microwave radars. It is important to make this distinction because differences exist between the two types of radar. Most of the current aviation weapons systems operate in the X band.

From table 10-1 it should be noted that an inverse relationship exists between the frequency (f) of the RF energy and the wavelength (λ).

The wavelength is the distance the wave of energy will travel during the time required for one cycle of oscillation; thus with a constant velocity, the higher the frequency, the shorter the wavelength and vice versa.

The Aviation Fire Control Technician may find it very helpful and sometimes necessary to determine either the frequency of the carrier or the wavelength when one or the other is known. This may be easily accomplished by using the following formula:

$$\lambda = \frac{300}{f}$$

where

λ = wavelength in meters

f = frequency in megahertz.

Thus, if

$$f = 10{,}000 \text{ MHz}$$

$$\lambda = \frac{300}{10{,}000}$$

$$\lambda = \frac{3}{100}, \text{ or } 0.03 \text{ m}$$

$$\lambda = 3 \text{ cm}$$

PULSE SHAPE AND WIDTH

In the case of a pulse type radar, the shape and width of the RF pulse influences minimum range, range accuracy, and maximum range. The ideal pulse shape would resemble a square wave having vertical leading and trailing edges. However, equipments do not usually produce the ideal waveforms.

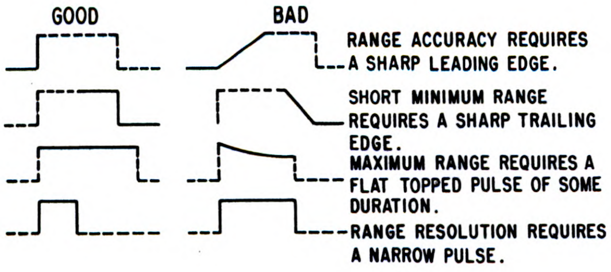
The factors influencing minimum range are discussed first. Since the receiver cannot receive target reflections while the transmitter is operating, it should be obvious that a narrow pulse is necessary for short ranges. A sloping trailing edge extends the width of the transmitter pulse although it may add very little to the total power generated. Therefore, along with a narrow pulse, the trailing edges should be as near vertical as possible.

A sloping leading edge also affects minimum range as well as range accuracy since it provides no definite point from which to measure elapsed time on the indicator time base. Using a starting point at the lower edge of the pulse's leading edge would increase minimum range. Using a starting point high up on the slope would reduce the accuracy of range measurements at short ranges which are so vital for accurate solution of the fire control problem.

Maximum range is influenced by pulse width and pulse repetition frequency (PRF). Since a target can reflect only a very small part of the transmitted power, the greater the transmitted power, the greater the strength of the echo that could be received. Thus, a transmitted pulse should quickly rise to its maximum amplitude, remain at this amplitude for the duration of the desired pulse width, and decay instantaneously to zero. Figure 10-5 illustrates the effects of pulse shapes.

PULSE REPETITION FREQUENCY (PRF)

Sufficient time must be allowed between the transmitted pulses for an echo to return from any target located within the maximum workable range of the system. Otherwise the reception of the echoes from the more distant


GOOD
BAD
RANGE ACCURACY REQUIRES A SHARP LEADING EDGE.
SHORT MINIMUM RANGE REQUIRES A SHARP TRAILING EDGE.
MAXIMUM RANGE REQUIRES A FLAT TOPPED PULSE OF SOME DURATION.
RANGE RESOLUTION REQUIRES A NARROW PULSE.

AQ.419

Figure 10-5.—Pulse shapes and effects.

targets may be obscured by succeeding transmitted pulses. This necessary time interval fixes the highest frequency that can be used for the pulse repetition. Both maximum and minimum pulse repetition frequencies for any radar set depend upon the tactical use that is to be made of the equipment. To reach great distances, the radar must be able to radiate plenty of power during the transmission of the pulse, and the rest cycle or waiting time must be long enough to allow the transmitted pulse to travel well beyond the maximum range of the radar and to return.

The time from the beginning of one pulse to the start of the next pulse (this includes the pulse and the waiting time for the return of that same pulse) is the pulse repetition time (PRT). It is the reciprocal of the pulse repetition frequency; that is,

$$\text{PRT} = \frac{1}{\text{PRF}}$$

From this relationship it can be seen that a radar set having a pulse repetition frequency of 400 pulses per second has a pulse repetition time of 1/400 second, or 2,500 microseconds. This indicates that as far as the PRF is concerned, the maximum range of the radar is the distance a pulse can travel to a target and back in 2,500 microseconds. To be useful, radar range expressed in time must be converted to radar range expressed in miles. Since radio energy travels at a constant velocity of 162,000 nautical miles per second (186,000 statute miles) a transmitted pulse will travel 1 nautical mile in 6.18 microseconds. Remember that the pulse, to indicate a target 1 mile away, must travel a mile to the target and a mile back to the receiver. The pulse travels a radar mile; that is, a go-and-return mile, which requires 12.36 microseconds.

As a general rule, the pulse repetition frequency (PRF) determines the maximum range of a radar equipment. As previously mentioned, the time interval between the transmitted pulse and the return echo from the maximum workable range of a radar fixed the highest PRF which can be used for that radar. If the maximum workable range of the radar is 200 miles, then the pulse repetition time (PRT) is 2,472 microseconds (200 x 12.36 microseconds). (See fig. 10-6.) To obtain this, a PRF of $1/(2,472 \times 10^{-6})$, is approximately 405 pulses per second (pps) is necessary.

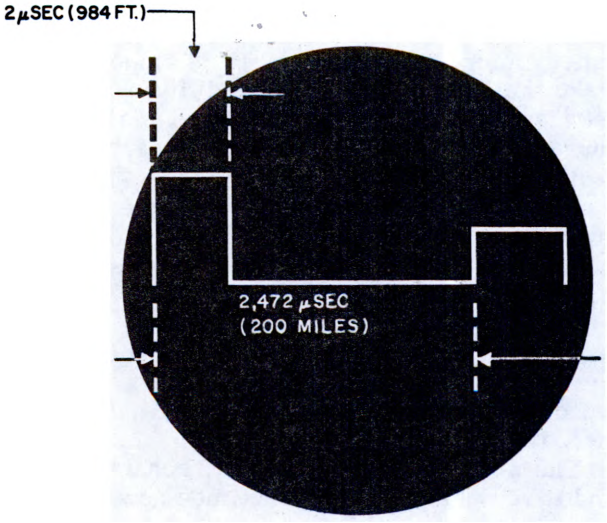


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Figure 10-6.—Pulse width, PRT, and range.

If, for some reason, the pulse of energy should travel farther than 200 miles and be reflected, it would return to the radar after the next pulse had been sent out. An echo from a target 250 miles distant would appear at the 50-mile point on the indicator sweep. How can the operator determine if this indication is from a target 50 miles away, or from a target 250 miles away that was reached by the preceding pulse? To eliminate "ambiguous targets," a lower PRF can be used. A PRF of 200 pps will give a PRT of 5,000 microseconds and a range of about 400 miles; that is, a pulse can travel out approximately 400 miles and return before the next pulse is transmitted. However, a sweep of only 200 miles is used on the indicator since that is the normal workable range. During the additional time, the sweep is blanked out. Any echo returning after 2,472 microseconds and up to 5,000 microseconds is not displayed.

The PRF must not be made too low. The speed of the antenna motion also has an effect on the minimum PRF. The radar beam strikes a target for a relatively short time during a revolution of the antenna. If the antenna rotates at 20 revolutions per minute, it completes a revolution in 3 seconds. During this time, the transmitter has fired 600 times if the PRF is 200 pps. If the beam width is 1°, during this 1° of rotation there will be less than 2 pulses sent out and echoes returned from a point target.

$$\frac{600}{360} = 1\ 2/3 \text{ pulses}$$

A sufficient number of pulses of energy must strike the target to return an echo that will be useful at the receiver. If the target is very narrow, the pulse may miss it entirely; and if it is very large, much of it will not show up on the scan.

POWER OUTPUT

Although the PRF does determine maximum range, it can be seen that range also depends largely on the power output of the set. It must radiate enough power so that the received echo signal at the maximum range will have a power level at least equal to the electronic noise in the receiver.

Radar systems have been developed to the degree where they transmit the largest peak power ever radiated by any type of radio transmitting equipment. This peak power is sometimes in excess of 10 megawatts and seldom less than 20 kilowatts.

The problems of generating and amplifying reasonable amounts of radio energy at extremely high frequencies and very high power levels are complicated by the physical construction of the electron tubes to be used. Tubes of special design must be used. Among these are such types as the magnetron, klystron, and traveling-wave tubes. In general, these tubes have low interelectrode capacitances, low transit time, and the ability to handle very high levels of RF power.

In considering power requirements, distinction must be made between two kinds of output powers—peak power which is the power during the transmission of a pulse, and average power which is the average power over the pulse repetition period. While the peak power is very large, the average power may be very small because of the great difference between pulse width and pulse repetition time.

The ratio of the pulse width to the pulse repetition period is known as the duty cycle. To convert peak power to average power, multiply the peak power by the duty cycle. The duty cycle is the fraction of total time that RF energy is being radiated and may be expressed as follows:

$$\text{duty cycle} = \frac{\text{pulse width}}{\text{pulse repetition period (T)}}$$

For example, a 2 μsec pulse repeated at the rate of 500 times per second represents a duty cycle of 0.001, since the time for 1 cycle is 1/500 second or 2,000 μsec.

$$1/500 = 0.002 \text{ seconds}$$

$$0.002 \text{ seconds} = 2{,}000 \times 10^{-6} \text{ seconds}$$

$$= 2{,}000\ \mu\text{sec}$$

Thus,

$$\frac{2}{2{,}000} = 0.001 = \text{duty cycle.}$$

Therefore, if peak power of a radar system is 200 kilowatts (kw) and average power = peak power x duty cycle

Then,

$$\text{average power} = 200 \text{ kw} \times 0.001$$

$$\text{average power} = 0.2 \text{ kw.}$$

Likewise, the ratio of the average power and the peak power may also be expressed in terms of the duty cycle as follows:

$$\frac{\text{average power}}{\text{peak power}} = \text{duty cycle}$$

Then, using the previous figures

$$\frac{0.2\text{ kw}}{200\text{ kw}} = 0.001 = \text{duty cycle}$$

The relationship of peak power, average power, duty cycle, pulse time, and pulse repetition period are illustrated in figure 10-7.

Still another method of finding the average power is by use of the following formula:

Average power = peak power x pulse width x pulse repetition of frequency

Thus, using the same figures as before

Average power = 200 kw x (2×10^{-6}) x 500
Average power = 0.2 kw.

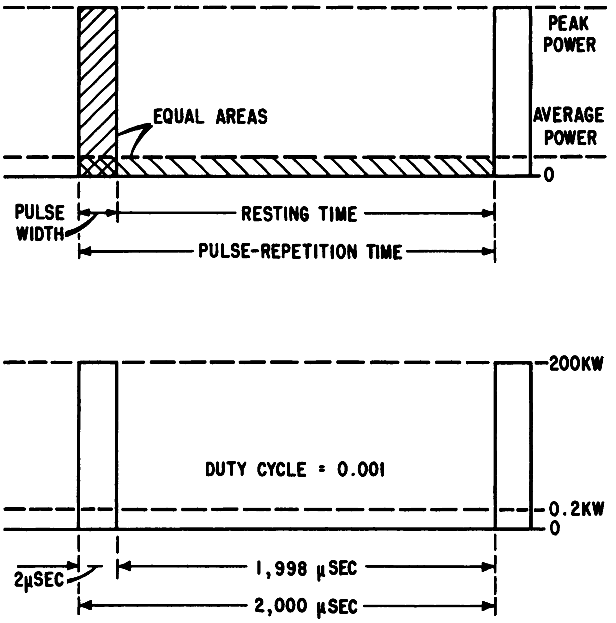

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Figure 10-7.—Relationships of peak and average power and duty cycle.

TRANSMISSION METHODS

There are three major radar transmission methods which use the basic principles as previously described. They are the frequency shift system (continuous-wave), the frequency-modulation system, and the pulse-modulation system. Emphasis has been placed on the pulse method in this chapter since it is very common in aviation weapons systems. The three major methods of transmission are described in the following paragraphs.

Continuous-Wave (CW) Method

The continuous-wave method operates on the principle of the Doppler effect. The Doppler effect is the apparent change in the frequency of light, sound, or electromagnetic radiation that is observed when the radiating source and the observer are in relative motion. This frequency shift is external to the transmitter; that is, the transmitter operates at a fixed carrier frequency. A common example of the Doppler effect is the changing pitch of the whistle of an approaching train. The train's whistle appears to change its pitch from a high tone as the train approaches to a lower tone as it moves away from the observer. As the train appraoches, there is an apparent increase in frequency—a rising of the pitch as the train moves away, there is an apparent decrease in frequency—a lowering of the pitch. This is the Doppler effect.

To examine the reason for this apparent change in pitch, assume that a transmitter emitting an audio signal at a frequency of 60 Hz is traveling at a velocity of 360 feet per second (fps). (See fig. 10-8.) Therefore, at the end of 1 second the transmitter will have moved from T to T1 in figure 10-8 (A). The total distance from T to O, the position of the observer, is 1,080 feet. The velocity of sound is 1,080 feet per second. Thus, a sound emitted at T will reach O in 1 second. To find the wavelength (λ) of the transmitted signal, divide the velocity of the signal (1,080 fps) by the frequency of the signal (60 Hz). The result is 18 feet.

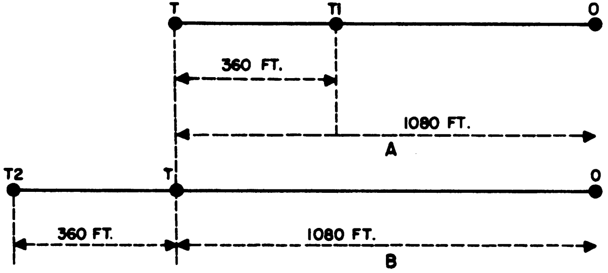

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Figure 10-8.—Transmitter moving relative to an observer.

It is known that in 1 second the transmitter moves 360 feet and transmits 60 Hz. At the end of 1 second the first cycle of the transmitted signal reaches the observer just as the 60th Hz is leaving the transmitter at T1. Under these conditions the 60 Hz emitted are between the observer and T1. Notice that this distance is only 720 feet (1,080 - 360). The 60 Hz spread over the distance from T1 to O have a wavelength which is only 12 feet (720/60). To find the new frequency, use the formula for frequency:

$$f = \frac{V}{\lambda}$$

$$= \frac{1,080}{12}$$

$$= 90 \text{ Hz.}$$

The original frequency of 60 Hz has changed to an apparent frequency of 90 Hz. This new frequency only applies to the observer at O. Notice that the Doppler frequency variation is directly proportional to the velocity of the approaching transmitter. The faster the transmitter moves toward the observer, the greater the number of waves that will be crowded into the space between the transmitter and the observer.

If the transmitter were stationary and the observer moving, the observer would encounter more waves per unit of time as he approaches the transmitter. As a result, he would hear a higher pitch than the transmitter was actually emitting.

When the transmitter is traveling away from the observer, as in figure 10-8 (B), the first cycle leaves the transmitter at T and the 60th at T2. The first cycle reaches the observer at O when the transmitter reaches T2. There are 60 Hz stretched out over 1,080 plus 360 feet, a total of 1,440 feet. The wavelength of these 60 Hz is 1,440/60, or 24 feet. Their apparent frequency is 1,080/24, or 45 Hz.

There are several applications of the continuous-wave, or Doppler system. In one radar application, the radar set differentiates between the transmitted and reflected waves, and thus determines the speed of the moving object. The Doppler method is the best means of detecting fast-moving objects that do not require range resolution. The Doppler effect here can be explained as follows: As a moving object approaches the transmitter, it encounters, and therefore reflects, more waves per unit time, just as an observer appraoching a transmitter receives more waves per unit time. The amount of the frequency shift is very small in relation to the carrier frequency, since the velocity of propagation of the signal is very high compared to the speed of the target. However, as the carrier frequencies used in radar are high, appreciable frequency shifts that are in the audio-frequency range are produced. The amount of shift is proportional to the speed of the reflecting target. One-quarter cycle shift at 10,000 MHz will give speed measurements accurate to a fraction of a percent.

The separation of the background and the target is based on this shift in frequency (Doppler effect) that is caused by the reflection of the signal from a moving target. A disadvantage of the system is that it does not determine the range of the target, nor is it able to differentiate between targets when they lie in the same direction and are traveling at the same speed. Moreover, it does not "see" stationary or slow-moving objects which a pulse radar system can detect. Doppler radar is covered later in this chapter.

Frequency-Modulation (FM) Method

In the frequency-modulation method, the transmitter radiates radio-frequency waves whose frequency is continually increasing and decreasing from a fixed reference frequency. At any instant, the frequency of the returned signal differs from the frequency of the radiated signal by an amount which is determined by the time it took the signal to travel the distance from the transmitter to the object.

An example of a frequency-modulated signal plotted against time is shown in figure 10-9. As shown, the 420-MHz frequency increases linearly to 460 MHz and then quickly drops to 420 MHz again. When the frequency drops to 420 MHz the frequency cycle starts over again.

Since the frequency regularly changes 40 MHz with respect to time, its value at any time during its cycle can be used as the basis for computing the time elapsed after the start of the frequency cycle. For example, at time t_0 the transmitter sends a 420-MHz signal toward an object. It strikes the object and returns to the receiver at time t_1, when the transmitter is sending out a new frequency of 440 MHz. At time t_1 the 420-MHz returned signal and the

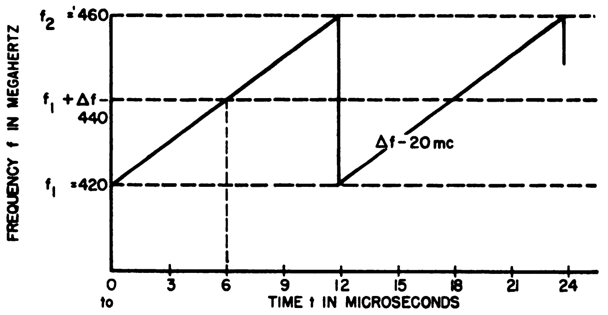

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Figure 10-9.—Frequency-modulation chart.

440-MHz transmitter signal are fed to the receiver simultaneously. When the two signals are mixed in the receiver, a beat note results. The frequency of the beat note varies directly with the distance to the object, increasing as the distance increases. A device that measures frequency can be calibrated to indicate range (distance to the object).

This system works well when the object is stationary. It is used in aircraft altimeters which give a continuous reading of the aircraft's true height above the earth. This system is not satisfactory for the location of moving targets, however, because moving targets produce a frequency shift in the returned signal because of the Doppler effect; this affects the accuracy of the range measurement.

Pulse-Modulation Method

Radiofrequency energy can also be transmitted in very short bursts called pulses. The pulses are of extremely short time duration, usually on the order of 0.1 microsecond to about 50 microseconds. In this method the transmitter is turned on for a very short time and the pulse of radio-frequency energy is emitted as shown in figure 10-10 (A). The transmitter is then turned off, and the pulse travels outward from the transmitter at the velocity of light (B). When the pulse strikes an object (C), it is reflected and begins to travel back toward the radar, still moving at the same velocity (D). The pulse is received by the radar (E) and the indicator computes the time interval between transmission and reception and converts this to a visual indication of range in miles or yards. The radar cycle then starts over again by transmitting another pulse (F).

Since this method does not depend on the relative frequency of the returned signal or on the motion of the target, it has important advantages over the continuous-wave and frequency-modulation methods.

FUNCTIONAL COMPONENTS

The functional breakdown of a pulse-modulated radar resolves itself into six essential components (fig. 10-11). These components are as follows:

1. The synchronizer (also known as the timer or keyer) supplies the synchronizing signals that time the transmitted pulses, the indicator, and coordinate other associated circuits.
2. The transmitter generates the RF energy in the form of short, powerful pulses.
3. The antenna system takes the RF energy from the transmitter, radiates it in a highly directional beam, receives any returning echoes, and passes these echoes to the receiver.
4. The receiver amplifies the weak RF pulses returned by the target and reproduces them as video pulses to be applied to the indicator.
5. The indicator produces a visual indication of the echo pulses in a manner that furnishes the required information.
6. The power supply provides the electrical power for the radar set.

While the physical configurations of radar systems differ, any radar system can be represented by the functional block diagram in figure 10-11. An actual radar set may have several of these functional components within one physical component, or a single one of these functions may require several physical components. However, the functional block diagram of a fundamental radar set may be used to analyze the operation of almost any radar set.

In the following paragraphs, a brief description of each of the major essential components is given. The individual circuits are discussed in more detail in chapter 11 of this manual.

SYNCHRONIZER

The synchronizer insures that all circuits connected with the radar system operate in a definite time relationship. It also times the interval between transmitted pulses to insure that the interval is of the proper length.

The pulse repetition frequency can be determined by any stable oscillator such as a sine wave oscillator, multivibrator, or a blocking oscillator. The output is then applied to necessary pulse shaping circuits to produce the

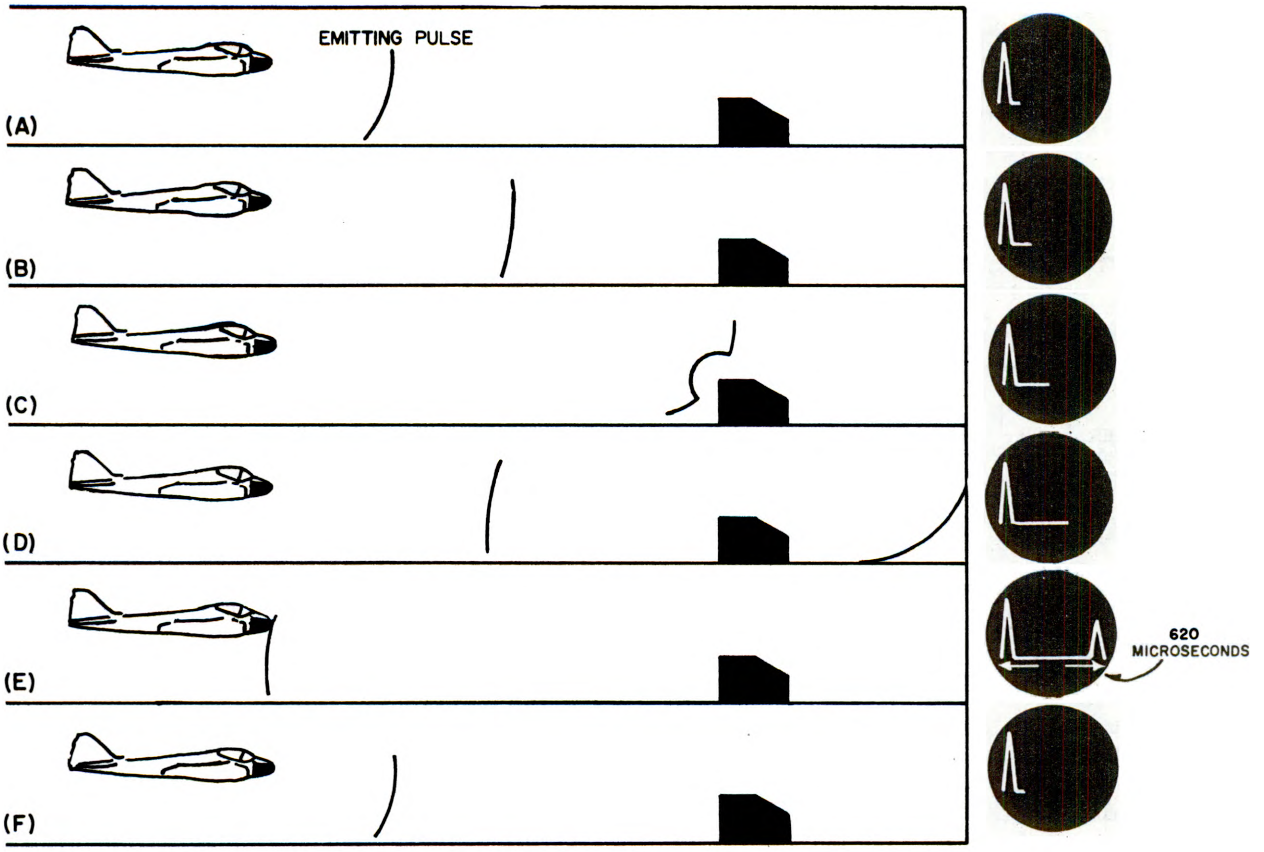

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Figure 10-10.—Pulse detection.

required timing pulse. Associated components can be timed by the output of the synchronizer or by a timing signal from the transmitter as it is turned on.

TRANSMITTER

The transmitter's main component is an RF oscillator using a tube of special design (such as a magnetron) which generates powerful pulses of RF energy at regular intervals. Since the resting time is very long compared to the transmitting time, the oscillator may be greatly overloaded during transmission time to increase the peak power. The oscillator requires operating power in the form of a properly timed, high amplitude, rectangular pulse. This pulse is supplied to the RF oscillator by a component called the modulator. The modulator supplies its high voltage pulse to either the plate or the cathode of the RF oscillator, depending on what type of tube is used as the oscillator. Normally, because of the very high voltage involved, the pulse is supplied to the cathode and the plate is grounded to shield personnel from shock hazards. The modulator switches the oscillator on and off. The modulator pulse applied to the oscillator may be more than 100,000 volts in some of the large early warning radars, or only a few hundred volts in some of the small airborne radars.

ANTENNA SYSTEM

The antenna system takes the energy from the transmitter, radiates it in a directional beam, picks up the returning echo, and passes it to the receiver with a minimum of losses.

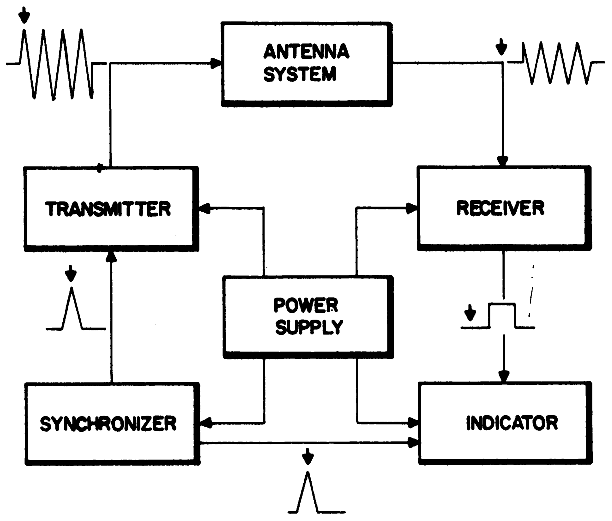

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Figure 10-11.—Functional block diagram of a fundamental radar system.

The antenna system includes the transmission lines and waveguide from the transmitter to the antenna, the antenna itself, the transmission line and waveguide from the antenna to the receiver, and any antenna-switching devices and receiver-protective devices that may be present.

Most radars now use parabolic-reflector (dish-shaped) type antenna systems. Figure 10-12 shows a parabolic-reflector type of antenna. This type of antenna is a practical means of producing a narrow beam pattern of microwave radiation. The reflection of RF energy by the paraboloid is closely analogous to the reflection of light by a parabolic mirror. A flashlight is an example of this effect. Many variations of the basic parabolic shape are used to obtain acceptable beam patterns for radars of different tactical uses.

When a radar receiver is operated close to a powerful radar transmitter, a certain amount of the transmitted signal inevitably finds its way into the receiver. In certain instances, such signals resulting from the main transmitted pulse must be entirely eliminated from the output of the receiver. Therefore, the receiver must be turned off, or gated, during the pulse time so that it will be completely insensitive. On the other hand, some radars are designed to permit a very small amount of the transmitter pulse to be coupled to the receiver for timing. Both of these conditions place a limit on the amount of transmitted pulse that can be permitted to reach the receiver; keeping the amount of "coupled" pulse to permissible levels is the job of receiver-protective devices.

Usually a radar antenna system has a single antenna and an antenna switch capable of connecting the antenna to the transmitter during the transmission time and to the receiver during the remainder of the pulse period. The switch is necessary to protect the receiver from the transmitter during the pulse time and to isolate the transmitter during the receiving time. Otherwise the weak echo signals might be wholly or partially lost in following the transmission line or waveguide back to the transmitter. The transmitted pulse width and the pulse repetition

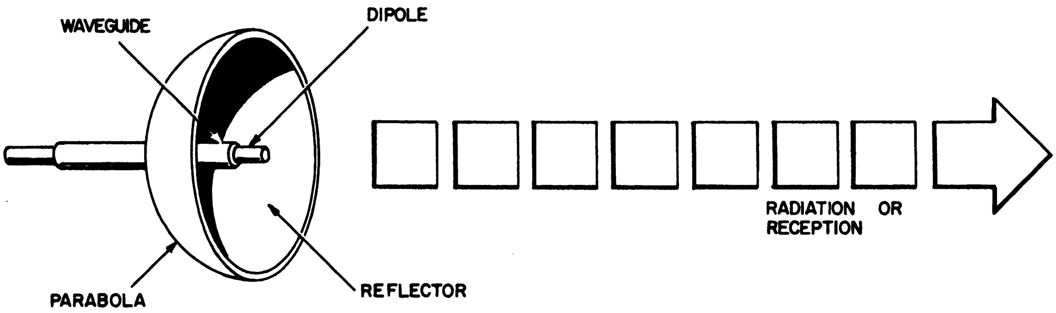

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Figure 10-12.—Parabolic-reflector type antenna.

frequency of the radar, which may be over 4,000 pps, eliminate the possibility of using a mechanical switch. The electronic device used to perform this switching is usually called a duplexer.

RECEIVER

The receiver takes the weak echo signals from the antenna system, amplifies them sufficiently, detects the pulse envelope, amplifies the pulses, and feeds them to the indicator. Since radar frequencies are very high, they are difficult to amplify. Therefore, one of the main functions of the radar receiver is to convert the frequency of the received echo signal to a lower frequency that is easier to amplify. This lower frequency is called the intermediate frequency (IF). The type of receiver that makes use of this frequency conversion is called a superheterodyne. Superheterodyne receivers used in radars must have good stability and extreme sensitivity. The stability of operation is insured by careful design, and the overall sensitivity is greatly increased by the use of many IF stages.

INDICATOR

The indicator uses the received signals obtained from the radar receiver to produce a visual indication of the desired information. The cathode-ray oscilloscope is an ideal instrument for the presentation of radar data, since it not only shows a variation of a single quantity such as voltage but gives an indication of the relative values of two or more synchronized variations. The usual radar indicator is basically the same in function as the low frequency test oscilloscope. The focusing, intensity, and positioning controls are similar. The sweep frequency of the radar indicator, however, is determined by the pulse repetition frequency of the radar, and the sweep duration is determined by the setting of the range selector switch.

POWER SUPPLY

In the general functional block diagram of a radar set, the power supply is represented by a single block. Functionally, this block is representative; however, one power supply may not meet all the requirements of a radar set. The distribution of the physical components of the system may be such as to make it impossible to place all the power supply circuits into one physical unit. Thus, different supplies may be needed to meet the various requirements of the set and must be designed accordingly. Essentially, the power supply converts the low voltage power from the aircraft's electrical system to voltages and currents suitable for the electronic circuits of the complete radar set.

OPERATING PROCEDURES

Due to the complexity and widely diversified types of aviation weapons systems in today's aircraft, it is quite difficult to establish any operating procedures as "standard." The item of greatest concern, of course, is safety—safety of the persons intending to operate the equipment, and safety in regard to the prevention of damage to the equipment. Many of the equipments installed in aircraft require special turnon and turnoff procedures. For this reason do not attempt to operate any equipment until a complete and thorough checkout has been received. Many safety precautions are general in nature and should be applicable regardless of the equipment. In the following paragraphs some of the operating procedures that might be applied to any system are described.

ENERGIZING

There are several items that must be considered before energizing any system in an aircraft. They are as follows:

1. Be thoroughly familiar with the equipment to be operated.
2. Make sure that all switches and controls are in their proper position before applying power. This includes those of ground support equipment as well as those in the aircraft.
3. Check to be sure that the application of power to the aircraft will not endanger other personnel working on or near the aircraft.
4. If radar is to be operated, insure that proper precautions are taken to prevent radiation from creating a hazard.
5. When auxiliary electrical power is to be used, make sure it is of the correct voltage, frequency, and phase, and that it is capable of handling the load to be placed on it.
6. Provide cooling air if required.
7. Be especially cautious when applying external hydraulic power.

DEENERGIZING

When deenergizing equipment that has been in operation, the following precautions should be observed:

1. All systems should be turned off before the external power is cut.
2. Except in an emergency, never remove an electrical power cable while it is "alive."
3. Leave all switches and controls in their proper position.
4. After the system has been deenergized, secure the aircraft in the manner approved.
5. Stow all power cables and return auxiliary equipment to its proper place.

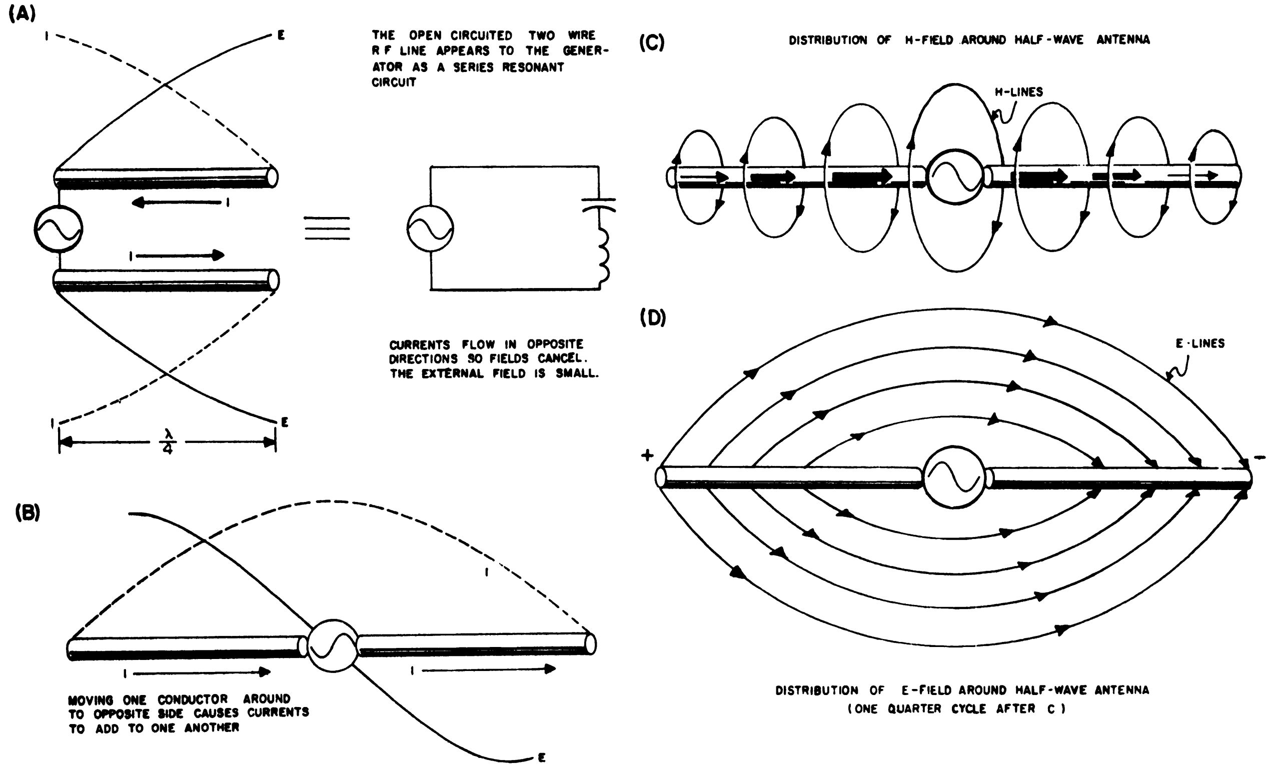
ELECTROMAGNETIC RADIATION

In order for the radio wave energy that has been generated by the transmitter to be of any use, it must be fed to the antenna where it can be "beamed" in the desired direction.

The principles of radiation of electromagnetic energy are based on the laws that a moving electric field creates a magnetic field and a moving magnetic field creates an electric field. The created field (either electric or magnetic) at any instant is in phase in time with its parent field, but is perpendicular to it in space. These laws hold true whether or not a conductor is present.

Because the half-wave dipole antenna is the fundamental element in an antenna system, it is used here as a starting point for discussing the radiation of electromagnetic energy into space. A review of this subject in Basic Electronics, NavPers 10087 (latest revision), which contains a detailed discussion of transmission lines, antennas, and propagation, is suggested at this time.

A dipole antenna can be developed from an open-end transmission line one-quarter wavelength long. Figure 10-13 (A) shows this quarter-wave section and the standing waves of current


(A)
I
E
THE OPEN CIRCUITED TWO WIRE RF LINE APPEARS TO THE GENERATOR AS A SERIES RESONANT CIRCUIT
I
I
CURRENTS FLOW IN OPPOSITE DIRECTIONS SO FIELDS CANCEL. THE EXTERNAL FIELD IS SMALL.
I
E
λ/4
(B)
I
I
I
E
MOVING ONE CONDUCTOR AROUND TO OPPOSITE SIDE CAUSES CURRENTS TO ADD TO ONE ANOTHER
(C)
DISTRIBUTION OF H-FIELD AROUND HALF-WAVE ANTENNA
H-LINES
(D)
E-LINES
+
-
DISTRIBUTION OF E-FIELD AROUND HALF-WAVE ANTENNA (ONE QUARTER CYCLE AFTER C)

AQ.427

Figure 10-13.—Development of half-wave antenna from open-end quarter-wave RF line.

and voltage developed on the line. The current flow, as indicated, is flowing in opposite directions in the two conductors. The magnetic fields, due to these currents, cancel. The electrostatic fields are also in opposite directions.

Efficient radiation requires a very heavy field density; therefore, the fields must reinforce, or aid, each other. Suppose the ends of the two conductors are spread apart. The direction of current flow does not change, but the magnetic field is being "opened" into space and less cancellation occurs. The electrostatic field is opened out instead of being concentrated in the small space between the two conductors. If the two conductors are moved until they are in line with each other as shown in figure 10-13 (B), the current flow in the two conductors is now in the same direction. The standing waves are exactly as they were before.

The magnetic (H) field about the wire is shown in figure 10-13 (C). The direction of current flow is indicated by the arrows, from left to right. The magnetic field is in the direction indicated. Since maximum change of current takes place at the center of the dipole, the magnetic field is greatest at the center. Figure 10-13 (D) shows the electrostatic (E) field about the conductor when the difference in potential between the ends of the conductor is the greatest. This does not occur at the same time as the maximum magnetic field. Since the voltage and current on the dipole are 90° out of phase, the electrostatic and magnetic fields surrounding the antenna are also 90° out of phase.

RADIATION SIMPLIFIED

There are many theories as to the why and how of radiation. While these theories are responsible for the advance in antenna design, they do not provide a simple and clear physical picture of the mechanics of radiation. The simplified physical picture does not tell the entire story, but the important fact to remember is that radiation does take place.

Figure 10-14 gives a simple picture of an E-field detaching itself from the antenna. The H-field is not considered, although it is present. In part (A) of the figure, the voltage is maximum and the electric field has maximum intensity. The lines of force begin at the end of the antenna that is positively charged and extend to the end that is negatively charged. Note that the outer E-lines are stretched away from the inner ones. This is due to the repelling force between lines of force in the same direction. As the voltage drops, the separated charges come together, and the ends of the lines move toward the center of the dipole as in (B). But, since lines of force in the same direction repel each other, the center of the lines is still being held out.

As the voltage approaches zero. some of the lines collapse back into the dipole; but in others, the ends of the line come together and form a complete loop. Notice the direction of these lines of force next to the dipole in part (C) of the figure. At this point the voltage on the antenna is zero. As the charge starts to build up in the opposite direction, electric lines of force

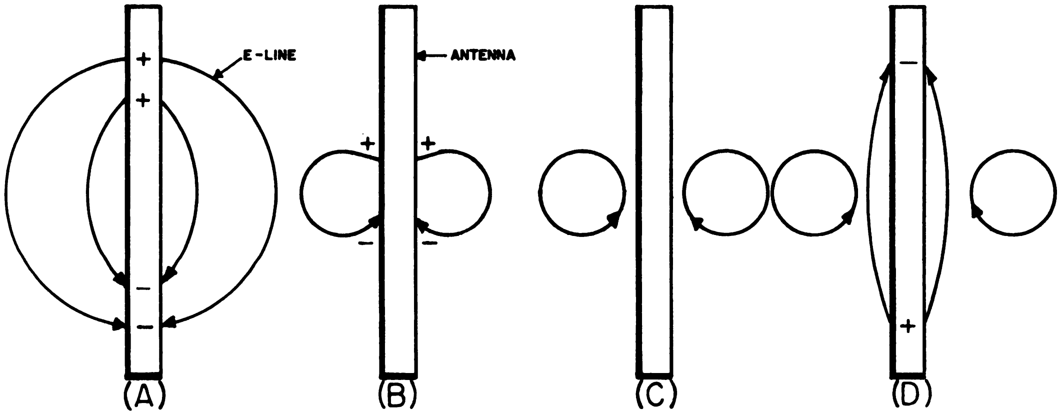


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Figure 10-14.—E-field detaching itself from an antenna.

again begin at the positive end of the antenna and stretch to the negative end (D). These lines of force, being in the same direction as the sides of the closed loops next to the antenna, repel the closed loops and force them out into space at the speed of light. As they travel, they generate a magnetic field in phase with them.

Another factor to remember about radiation is the ease with which it may occur varies with frequency. At lower frequencies, such as 60-Hz power frequencies for example, voltage on the antenna changes so slowly that the component of energy radiated is extremely small and is of no practical value. At higher frequencies, such as 50,000 Hz and up, the radiated energy is great enough to meet communications requirements.

RADAR BEAM FORMING

As previously mentioned, the ease with which radiation occurs varies with frequency. As the transmitting frequencies become higher, the wavelength becomes shorter, until the energy waves become more like light waves. In the microwave region, the wavelengths are measured in centimeters and the energy waves travel in straight lines as do light waves. This means that they can be focused and reflected just as light rays can. This is fortunate because, for purposes of airborne armament control radar, it is essential that the energy waves be radiated in a concentrated beam instead of allowing the waves to escape in all directions as is often done with communications or radar beacon transmissions.

There are several methods of forming the radiated energy into directional patterns. These are described in Basic Electronics. There is one problem that still remains when using most methods of beam forming. This is the fact that even though the wave is directional, the front is also spherical. A spherical waveform spreads out as it travels because the energy travels in a direction perpendicular to the wave front. This produces a pattern that is not too sharp. On the other hand, a "plane" wave front does not spread out because all the wave front moves forward in the same direction. For a sharply defined radar beam, it is necessary to change the spherical wave front into a plane wave. One way to accomplish this is by the use of a parabolic reflector. This method is similar to that used to focus the light rays of an automobile headlight. In an example such as this, the light source is placed at the focal point. Light rays striking the parabolic reflector are reflected at angles that result in parallel paths for all the light rays. The same thing can be done with microwaves. Light rays require a highly polished surface, while microwaves can be reflected by a comparatively large metal surface.

In figure 10-15, a directional source of radiation is placed at the focal point F. The field leaves the source with a spherical wave front. As each part of the wave front reaches the reflecting surface, it is shifted 180° in phase and is sent outward at angles that cause all parts of the field to travel in parallel paths. Because of the shape of a paraboloid surface (paraboloid), all paths from F to the reflector and back to line XY are the same length. Therefore, all parts of the field arrive at line XY at the same time after reflection, forming a plane front, and beam sharpness is maintained.

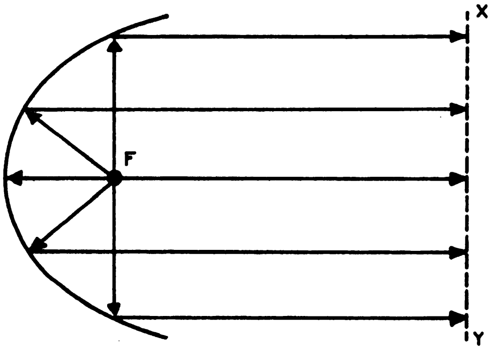

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Figure 10-15.—Forming a plane wave front.

POLARIZATION

How polarization works can perhaps be illustrated most readily by again using light as an example. Light rays, before passing through a polarizing material, vibrate in many directions; they have simultaneous random components of polarization. The polarizing material allows only those waves vibrating in a certain direction to pass through, blocking all the others. The result is a reduced signal in which all of the waves vibrate in the same direction; they are polarized. If, for example, a ray of light that is vertically polarized is passed through a vertically oriented polarization-sensitive filter, there is no attenuation. This same wave would be stopped almost completely if the filter was to be positioned so as to pass only horizontally polarized waves.

If light with random polarization is first polarized by passing it through a polarizing filter, then passed through a second filter which can be rotated with respect to the first, the amount of light permitted to pass could be precisely controlled. The operation of this principle also applies to radio or radar waves.

Linear Polarization

Polarization of an electromagnetic wave is the directional characteristic of the electric or magnetic field of a wave. In radio/radar work the electric field is normally used as the reference which determines the direction of polarization; that is, if the electric lines are horizontal, the wave is said to be horizontally polarized (fig. 10-16 (A)). If the E-lines are vertical, the wave is said to be vertically polarized (fig. 10-16 (B)). The horizontally positioned antenna produces and receives a horizontally polarized wave, and the vertically placed antenna produces and receives a vertically polarized wave. Polarization as just described is called linear polarization.

Circular Polarization

A factor that determines the effective range of a radar set is the manner in which the RF energy is radiated into space. The radiation of electromagnetic energy during normal weather conditions gives good target returns. However, during a heavy rainstorm, the individual raindrops act as targets and reflect the polarized electromagnetic energy, which may completely

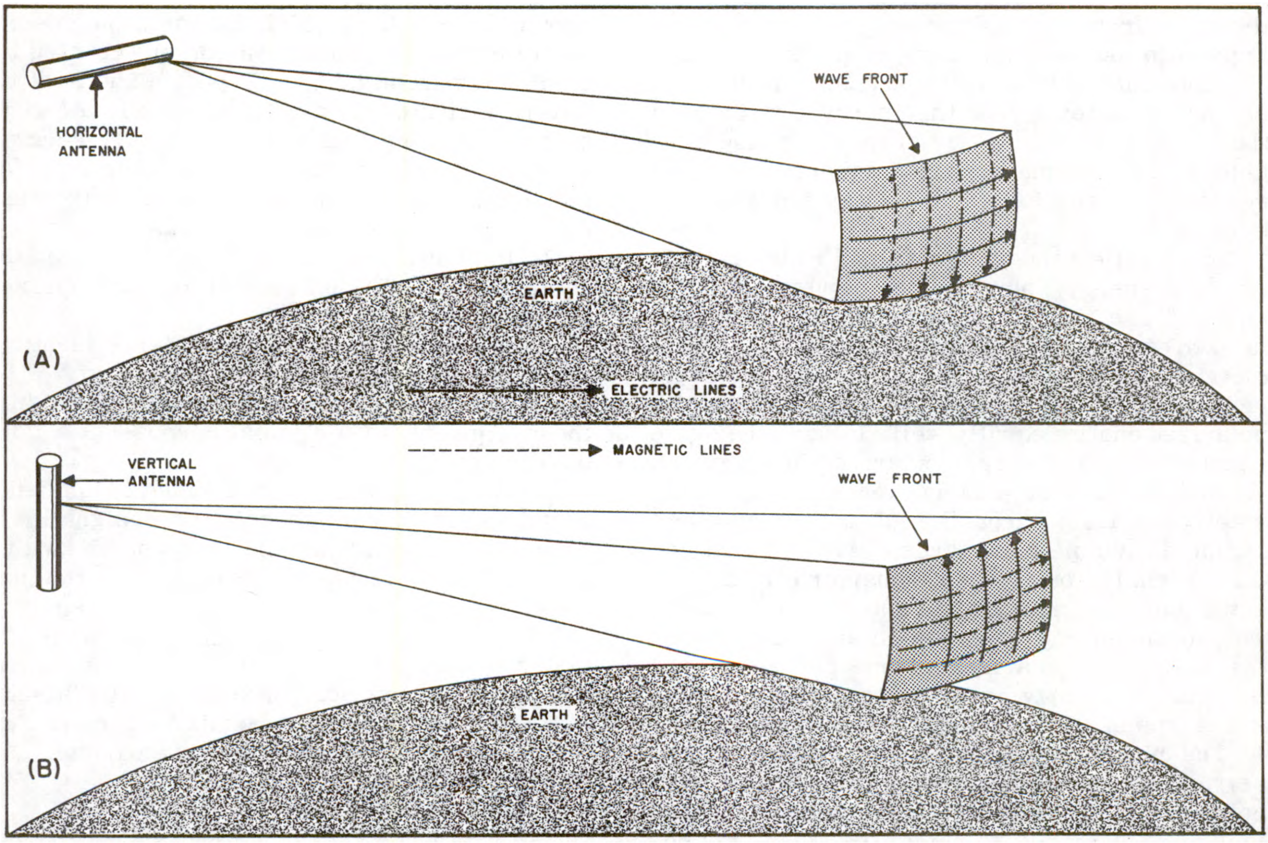

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Figure 10-16.—Linear polarized waves.

illuminate or "clutter" the indicator and obscure any target that may be in the area. This condition is undesirable and is overcome by radiating energy in a type of polarization that is designed to cancel returns from symmetrical targets, such as raindrops. This type of polarization is known as circular polarization.

To visualize the transmission of energy in such a manner, imagine the electric lines of force in vertical polarization being changed from their fixed position in space and rotated through 360° with every cycle of RF energy fed to the antenna. This will produce constant amplitude electric lines of force which are continuously changing their angular position as they are radiated into space. The resulting effect is a circular motion of the electric field and produces circular polarization.

Normally when a reflecting surface is hit by a cycle of RF energy, currents are induced in the reflector. These induced currents, in turn, cause the reflecting surface to act as a transmitting antenna, radiating a cycle of energy at the same frequency as the original energy, polarized in the same plane but reversed in phase. The intensity of this reflected energy is dependent on the intensity of the energy that induced the current, the efficiency of the reflecting surface as an antenna at that frequency, and the response of the target to energy polarized in that plane.

Some reflectors are very good radar reflectors for energy polarized in the vertical plane and yet are poor targets for horizontally polarized energy at the same frequency. Symmetrical reflectors, such as spheres, however, respond to both vertically and horizontally polarized energy equally well. In fact, they give equal response to energy polarized in any plane. When the plane of polarization changes, constantly rotating through 360° with each cycle radiated, symmetrical targets give constant returns. On the other hand, nonsymmetrical targets, such as aircraft, do not respond equally well to the energy polarized in any plane. When the energy is polarized in one plane, the reflected energy may be very weak. This results in returns of different amplitudes.

The piece of equipment that changes either vertical or horizontal polarization to circular polarization is called the polarizer. The polarizer is designed to reject the circularly polarized waves reflected by symmetrical targets, such as raindrops, and accept the energy reflected from nonsymmetrical targets.

RADAR NOMENCLATURE

Nomenclature designations are used primarily as the short title of equipments. These designations are also unclassified, whereas the actual name of the equipment may be classified.

The nomenclature system used by the military services to identify electronic equipment (including test equipment) is called the Joint Electronics Type Designation System (AN system) for communications and electronic equipment. The system is designed so that its indicators will tell at a glance many things pertinent to the item. For example, it tells whether the item is a set or a component (unit) and such other information as where it is used, the kind of equipment, and its purpose. The indicator for a complete set begins with the letters AN. This is followed by a slant bar and a three-letter group. The three-letter group gives the general nature of the installation, the type of equipment, and the purpose of the equipment, respectively. Following the three-letter group is a number, which indicates the specific model of the equipment. An example of an equipment designation is AN/APQ-72. The first two letters indicate that this equipment is identified by the AN nomenclature system. By checking appendix IV, it can be seen that the letters following the slant bar identify this equipment as a special purpose airborne radar as follows:

1. In column one, the letter A identifies this equipment as one that is installed and operated in an aircraft.
2. In the next column, the letter P identifies the equipment as radar.
3. In the last column, the letter Q describes the equipment as a special purpose or a combination of purposes.

When the system just described is applied to a unit of the complete set, the designation is formed by replacing the letters AN with a letter-number group which indicates the type and model of the unit in question appendix V, presents commonly used unit indicator letters that are used in the letter-number group. An example of a unit designator would be SN-233/APQ-72. By checking appendix V, it can be determined that this unit is the synchronizer used in the APQ-72 radar set.

ANALYSIS OF OPERATION

The fundamental fire control problem is to determine the correct direction to aim the weapon in order to insure a hit when the target is within range. To do this, it is necessary to find the target, lock on to the target, and track the target.

SEARCH PHASE

The limitations of visually detecting a small aerial target at considerable range are apparent. Among the factors which contribute to the limitations of visual means are:

1. The difficulty of detecting a small spot within the large aerial volume in front of an aircraft.
2. The difficulties imposed by adverse weather.
3. The difficulties imposed by night operations.
4. The physical strain upon pilot and/or crew of continuous examination of large areas of air and surface.
5. The already complicated task of flying high-speed, high performance aircraft.

Because of these limitations on visual means, the most common means of searching for a target by an aviation weapons system is radar.

Radar gives accurate target information even though the target may be hidden by darkness or fog, and also supplies information which may be used for the determination of the correct lead angle for hitting the target. To determine a target's position, the distance or range to the target, its elevation relative to the aircraft, and its relative bearing must be known. Radar gives all three of these spatial coordinates.

The initial contact with the target is usually made by the radar when it is operating in its search function. Radars designed for search operation are capable of continuously observing a large aerial volume either surrounding or in front of the aircraft. The outstanding advantage of radar search is its freedom from restrictions regarding visibility and lighting. Radar, too, has disadvantages. The most serious is the probability of interception by an enemy detection unit. Because radar energy drops off as the square of the distance, radar signals can be detected at least four times as far as a radar can detect targets.

The high speed of present day targets requires that search and detection be carried out to a long range. The search radar examines the searched area by the rotation or oscillation of a directional antenna, which successively illuminates all portions of the search area.

Besides the possibility of using the radar within the aircraft for detecting the targets, systems have been developed where the interceptor is "vectored" to the approaching enemy or unknown aerial target by means of another airborne radar, whose only purpose is to search for aircraft, and identify them, and vector air interceptors to engage hostile aircraft.

TRACKING PHASE

In today's high-performance aircraft, the pilot has little time to devote to the fire control problem. This makes it imperative that some means be provided to aid the pilot in establishing the range to the target. Radar is ideally suited to this purpose. It measures range quickly and accurately and supplies a proportionate input to the ballistics computer.

Range can be indicated on a meter or cathode-ray tube calibrated in feet, yards, or miles. Where a cathode-ray tube is used to present range information, range rate can be presented also. Where ranging radar is used in forward-firing weapons systems, a means is also provided to warn the pilot when he is within firing range and when breakaway range is reached. The warning to the pilot may be a 400 Hz or 1,200 Hz tone in his headphones or a suitable cathode-ray presentation. This enables the pilot to concentrate on tracking the target. Tracking is usually done in conjunction with ranging of the target. Once the target is within range, it must be tracked to obtain the information necessary to accurately aim the weapons.

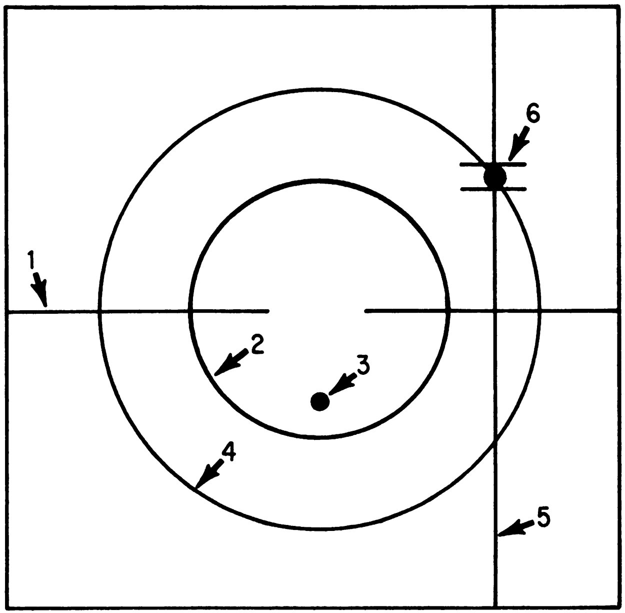
There are several different systems in use at the present time that depend upon radar for tracking. They differ mainly in the amount of automation and in the manner in which tracking information is relayed to the pilot. The two major methods for relaying this information from the radar are by means of a cathode-ray tube, and an optical sight system.

The radar method uses radar for tracking and the cathode-ray tube for displaying the information. During air intercept (AI) search operation, the radar maintains a constant surveillance over the space in front of the aircraft with target echoes displayed on the scope (cathode-ray tube). By means of a manual control on the radar, the pilot may select for automatic tracking any target appearing on the scope.

This selection of a target for automatic tracking is accomplished by positioning acquisition symbols.

The pilot positions the acquisition symbols by a position control on the radar until it brackets the target. However, the antenna continues its regular search scanning until the pilot operates a lock-on control. This control initiates automatic tracking of the target in range, azimuth, and elevation. The antenna then ceases its regular scan and is driven until it coincides with the target's azimuth and elevation positions. The target may be rejected by operating the lock-on control during the automatic tracking phase.

During automatic tracking, the presentation on the scope differs greatly from that during search. Figure 10-17 shows a scope presentation during track mode. The bearing of the target from the flightpath is represented by the B sweep (5). The range gate (6) indicates miles to the target. The range rate circle (4) gives an indication of opening or closing velocity. The steering error dot (3) indicates to the pilot the direction to fly the aircraft to point it at the target. When the steering error dot is within the missile performance circle (2), a missile may be fired and in all probability will hit the enemy aircraft.



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1. Aritifical horizon.
2. Missile performance circle.
3. Steering error dot.
4. Range rate circle.
5. B sweep.
6. Range gate.

Figure 10-17.—Scope presentation of track mode.

MONOPULSE RADAR

The methods of scanning studied so far are often called sequential scanning because target information must be gathered from a series, or sequence of pulses. Another scanning technique called MONOPULSE, or SIMULTANEOUS LOBING, can obtain the same target information from a single pulse.

In the monopulse system that will be considered, the radar radiates a single beam, whose axis coincides with the antenna axis. Normally, with a single beam fixed with respect to the antenna, a target would move a substantial distance from the antenna's axis before the radar's tracking system would detect an error and react. To track a moving target, an error signal is necessary. Error signals are obtained by comparison. In conical scanning, the error signal is obtained by comparing the strength of the echo returns from successive pulses. In the monopulse system the pulse is divided into four separate parts in the waveguide system. The four parts are radiated by four separate feedhorns and are combined by the antenna into a single beam. Returned echoes are divided again into four parts. The relative strength of the parts is compared to obtain target position with respect to the antenna axis.

The heart of this monopulse system is the microwave comparator. It consists of four feedhorns, four hybrid rings, and their connecting waveguide sections.

Figure 10-18 shows a hybrid ring microwave comparator. The symbol delta (Δ) stands for difference or subtraction, and the symbol sigma (Σ) stands for sum or addition.

The microwave comparator shown in figure 10-18 receives the track target return signal from the four horns A, B, C, and D and from them derives three component microwave signals, conveying information on the range of the target and its angular displacement from the boresight axis in azimuth and elevation.

If the target is above the boresight axis, the signals received by the two lower horns C and D are stronger than those received by the upper horns A and B. If the target is to the left of the

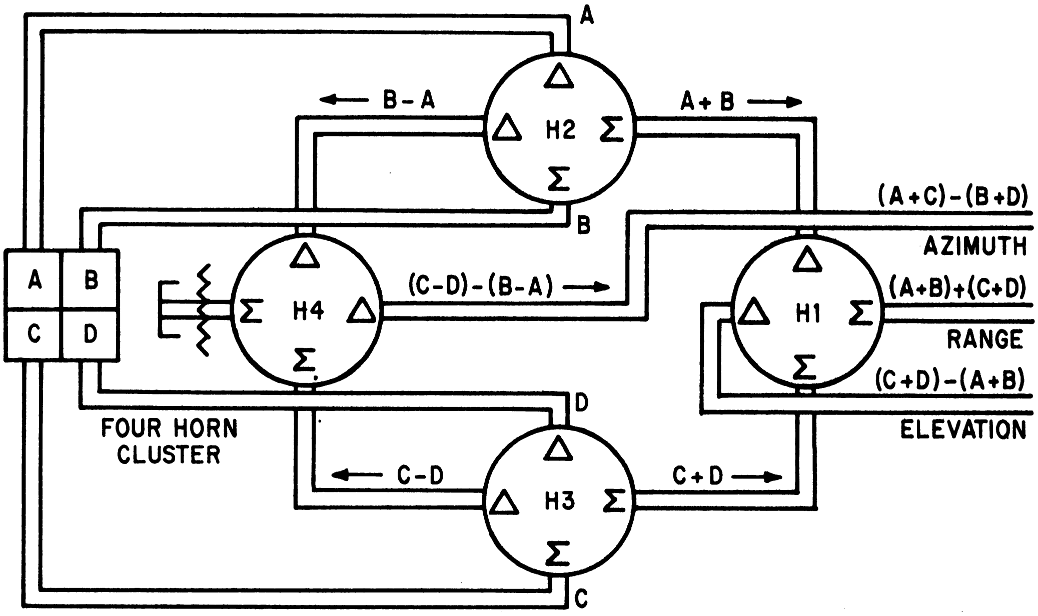

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Figure 10-18.—Hybrid ring microwave comparator.

boresight axis, the signals received by horns A and C are stronger than those received by horns B and C. The three output signals from the comparator are obtained by addition and subtraction of these signals.

The sum signal, obtained by summing the outputs of the four horns, serves as a reference for the amplitude and phase of the other two signals; this is accomplished in the receiving circuits. Its amplitude is practically unaffected by small angular displacements of the target from the boresight axis. The four horn signals are added by hybrid rings H1, H2, and H3. The output signals of horns A and B are applied to opposite arms of H2. Their sum, A + B, appears at the remaining Σ arm of ring H2 and is applied to one of the Δ arms of ring H1. In the same manner, ring H3 forms the sum C + D and applies it to the Σ arm of ring H1 that is opposite the Δ arm to which the sum A + B is applied. The sum (A + B) + (C + D) appears at the remaining Σ arm of H1. This is the sum signal.

To indicate the target displacement up or down from the boresight axis, the strength of the signal received by horns A and B is compared with that of the signal received by horns C and D. The sums A + B and C + D are applied, as previously described, to opposite arms of H1. The elevation signal, the difference (C + D) - (A + B), appears at the remaining Δ arm of H1. An arbitrary convention determined that (C + D) is the positive term. When the target is above the boresight axis, the signal (C + D) is stronger than (A + B) (remember the inversion in the lens) and the azimuth signal is considered to be in phase with the sum signal.

To indicate the target displacement to the left or right of the boresight axis, the comparator forms the azimuth difference signal (A + C) - (B + D). When the target is to the left of the boresight axis, A + C is greater. To form this difference signal, the signal B-A that appears at the Δ arm of ring H2 is applied to a Δ arm of H4. Likewise the difference C-D, supplied by H3, is applied to the opposite arm or ring H4. The difference (C-D) - (B-A), when transposed, becomes (A + C) - (B + D). The sum signal that appears at the Σ arm of ring H4 is not used and is absorbed by a power termination.

The elevation and azimuth difference signals are compared in the radar receiver with the sum, or reference signal. The output of the receiver may be either positive or negative pulses. The amplitude is proportional to the displacement of the target from the boresight axis, and the polarity indicates the direction of displacement. If there is no tracking error, the output is zero.

The monopulse system provides direct amplitude comparison of the RF signals. Hence, noise generated by the local oscillator and produced in the IF amplifiers has less effect on the angle tracking system.

DOPPLER RADAR

Doppler radar is used primarily in airborne navigation. It provides groundspeed and drift, which can be used to update inertial navigation position. Doppler radar has also found wide use as guidance device for guided missiles, and most moving target indicator (MTI) pulsed radars also utilize the Doppler principle to emphasize moving targets and cancel stationary targets.

A requisite for any Doppler radar is coherence; that is, some definite relationship must exist between the transmitted frequency and the reference frequency which is used to detect the Doppler shift of the received signal. In continuous-wave systems, the Doppler frequency is obtained by heterodyning the received signal with a portion of the ever present transmitter signal. When this is done, a separate coherent reference is not required because the reference is the transmitting frequency itself. In the incoherent system beams are radiated both forward and aft and the RF pulses are incoherent from pulse to pulse. Because of the aircraft velocity with respect to the ground, the forward beam signal returns will have increased in frequency and the aft beam returns will have decreased in frequency. The two beam signals are heterodyned and their difference, which is twice the Doppler frequency shift of one beam, is detected. In this case one beam acts as the reference for the other beam. This is called incoherent Janus. (Janus was a Roman god who had two faces, one looking forward and one looking aft.)

Theory of Operation

The Doppler effect is the increase or decrease in frequency of a received signal from that of a transmitted signal. The frequency shift may result from either the transmitter or the receiver moving toward or away from each other, or from the movement of a confined transmitter-receiver relative to a fixed reflecting surface. Disregarding angular motion, the amount of the frequency shift is directly proportional to the closing or receding velocity along a straight line distance between the transmitter and receiver, or between the combined transmitter-receiver and fixed reflecting surface. The orientation of the antenna beam patterns relative to the horizontal and vertical planes is illustrated in figure 10-19. All the energy reflected from the ground at an angle γ undergoes the same Doppler frequency shift, Δf, as can be seen from the basic Doppler equation.

$$\Delta f = \frac{2V}{c} f_T \cos \gamma$$

where

Δf = frequency shift

f_T = transmitted frequency

V = ground speed of aircraft

c = speed of light (constant)

γ = vertical depression angle of transmitted energy.

As the angle γ changes, but all other parameters are kept constant, Δf, the Doppler frequency shift changes. If energy were radiated in a conical pattern, the resultant beam would intersect the ground in a hyperbola. If the γ angle were changed, the resulting family of conical beams (one for each value of γ) would intersect the ground in a family of hyperbolas (one hyperbola for each value of γ). The hyperbola, shown in figure 10-20 would, therefore, be lines of equal Doppler frequency shift. The beam corresponding to a γ of 90° would be transmitted directly downward and would intersect the ground in a straight line; the energy returned from this beam would show zero Doppler shift, since $\cos 90° = 0$.

It follows that if the antenna is astride ground track, as in figure 10-20 (A), the Doppler frequency shift in the left beam is equal to the Doppler frequency shift in the right beam. If the antenna were off ground track to the left, for example, as shown in figure 10-20 (B), the return from the left beam pair would indicate a lower frequency than the return from the dark

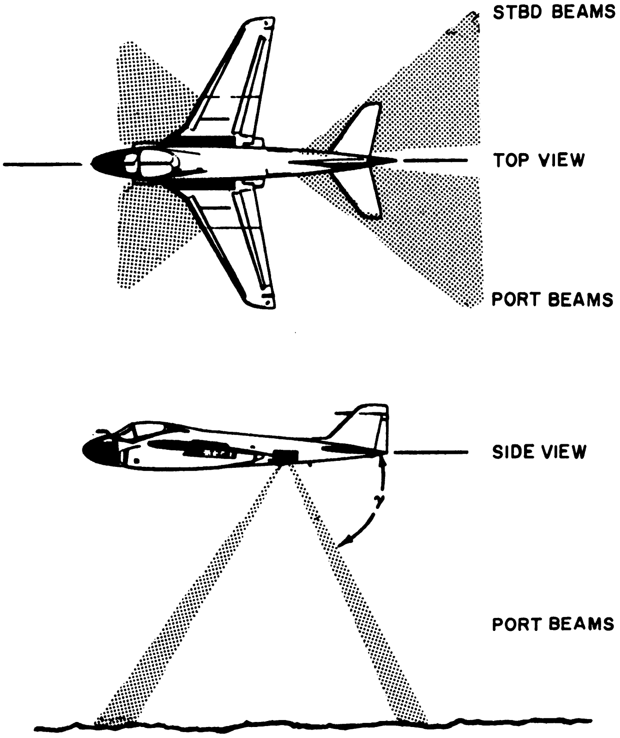

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Figure 10-19.—Doppler radiation pattern.

beam pair. (Note that the left front and right rear beams would be closer to the zero frequency-shift line.) The drift computing elements would sense this difference in frequency shift and utilize it as an error signal to servo the antenna to ground track. When the antenna is on ground track, the returns from the right and left beams exhibit equal frequency shifts. At this point, the error signal to the servo is zero, and the antenna is held on ground track. The angle (relative to the aircraft's longitudinal axis) through which the antenna has been turned to aline it with the ground track is equal to the drift angle. Each beam of the antenna pattern is about 5 1/2° wide (at the half power points) in the narrow direction and 30° wide in the lower direction (fig. 10-19). Because of the 30° beam width, all parts of the reflected energy from any one of the four segments do not return at the same time. Thus, in passing over hilly terrain, the possibility of losing coherence between the front and rear beams (by having all the energy of either beam return at a different time from the energy of the other beam) is diminished.

Doppler Radar Navigation System

A typical Doppler radar navigation set consists of three major functional units: a receiver-transmitter, an antenna assembly, and a signal data converter. The set utilizes a four beam, pulsed, incoherent, Janus transmission. It beams signals to the ground, receives echoes, and measures the frequency shift produced by the relative motion between the aircraft and the earth. The system is pulsed so that only two beams (diagonally opposite) are transmitted and received at a time. Aircraft motion shifts the forward beam up in frequency and the rearward beam down in frequency. The frequency shift sustained by each pair of beams is measured and compared. The analog voltage of the difference in frequency shift drives the antenna in azimuth until the frequency shift from each pair of beams is equal. When this occurs, the antenna is alined with the aircraft's track over the ground. The drift angle indication is the resultant angle between the antenna axis and the aircraft axis. Once the antenna is alined with the ground track of the aircraft, the measured frequency shift in received echoes is utilized to derive groundspeed. The Doppler derived drift angle and groundspeed analog signals are transformed within the signal data converter to digital outputs that are subsequently provided to the digital ballistics computer.

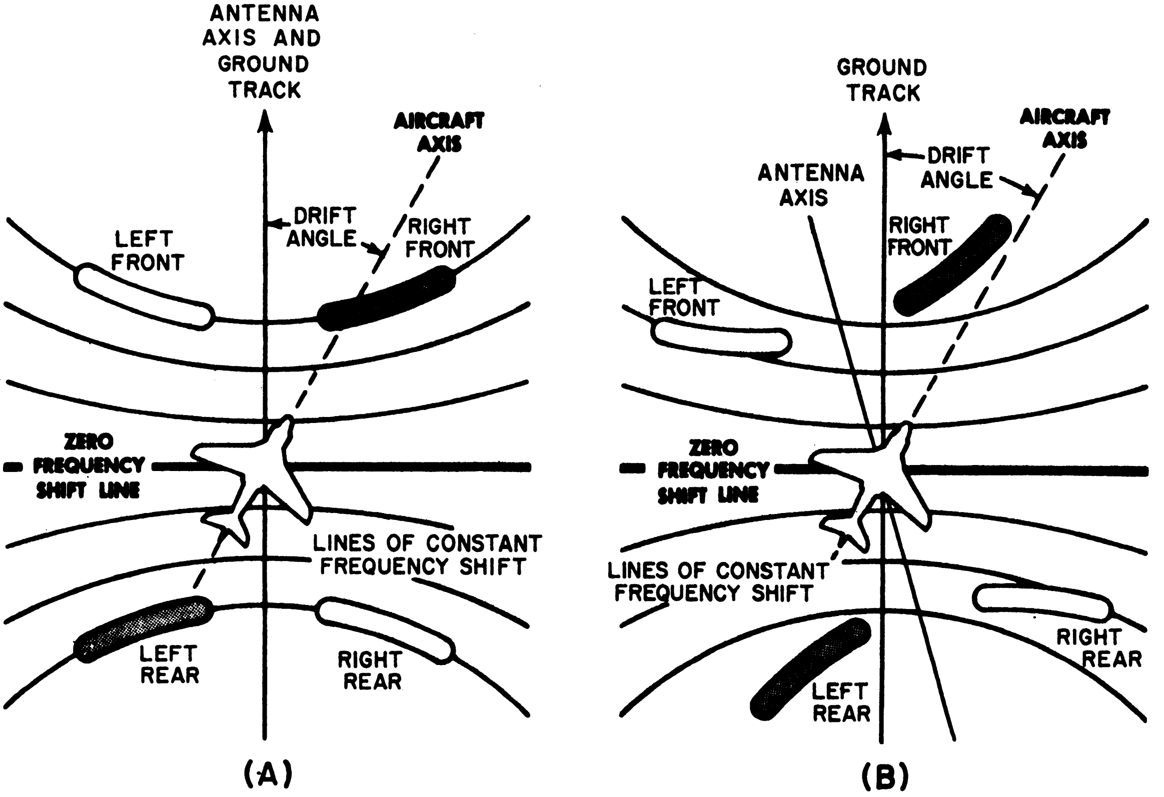

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Figure 10-20.—Doppler frequency shift. (A) Antenna illumination pattern, antenna astride ground track; (B) antenna not astride ground track.

CHAPTER 11

RADAR CIRCUITS

A radar system consists of a transmitter which sends out RF signals, a receiver which is located at the same site, and an indicator which gives a visual indication of echoes returned by the target. To accomplish this, many circuits, some of which are special, are required.

The circuits described in this chapter are those of a typical pulsed type radar. The major components receiving particular emphasis are the synchronizer, transmitter, receiver, and indicator.

SYNCHRONIZER

The basic function of the radar timer is to synchronize the sweep voltage or current for the indicator with the transmitter pulse. The specific function is to produce the trigger pulse that starts the transmitter, the sweep circuits, rangemark generators, blanking circuits, and gating circuits.

Timing or control is the function of the majority of the circuits in radar. Circuits in a radar set accomplish this function by producing a variety of voltage waveforms, such as square waves, sawtooth waves, trapezoidal waves, rectangular waves, brief rectangular pulses, and sharp peaks.

In sound and in radio, tubes operate within the limits for which they are designed; but in radar timing circuits, they are often violently overdriven, frequently operating at points which range from well in the grid current region to far beyond cutoff. Although all of these circuits are broadly classified as timing circuits, the specific function of any individual circuit might be timing, waveshaping, or wave generating.

Radar systems may be classified as either self-synchronized systems, or externally synchronized systems. In a self-synchronized system, the timing-trigger pulses are obtained from the transmitter. In an externally synchronized system, the timing trigger pulses are obtained from a master oscillator, which is usually external to the transmitter. The master oscillator may be a sine-wave oscillator, an astable (free-running) multivibrator, or a blocking oscillator.

When a blocking oscillator is used as a master oscillator, the timing-trigger pulses are usually obtained directly from the oscillator. When a sine-wave oscillator or an astable multivibrator is used as a master oscillator, pulse-shaping circuits are required to form the necessary timing-trigger pulses.

In a self-synchronized radar system, the repetition rate of the timing-trigger pulses is determined by the repetition rate of the modulator (or transmitter) pulses. In an externally synchronized radar system, the repetition rate of the timing-trigger pulses from the master oscillator determines the pulse repetition rate of the transmitter.

Associated with every radar system is an indicator, such as a cathode-ray tube. The indicator presents target data (range, bearing, and elevation) in visual form so that the target may be located. Trigger pulses from the timer (synchronizer) are frequently used to produce gate pulses. When applied to the indicator, these gate pulses perform the following functions:

1. Initiate and time the duration of the indicator sweep voltage.
2. Intensify the cathode-ray tube electron beam during the sweep period so that the echo pulses may be displayed.
3. Gate a range marker generator so that range marker signals may be superimposed on the indicator presentation.

(NOTE: The terms marks and markers are normally interchangeable.)

Figure 11-1 shows the time relationship of the various waveforms in a typical radar set. The timing-trigger pulses are applied to both the transmitter and the indicator. When a trigger pulse is applied to the transmitter, a short burst, or pulse, of RF energy is generated.

This energy is conducted along a transmission line to the radar antenna, from which it is radiated into space. If the transmitter energy strikes one or more reflecting targets in its path, some of the transmitted energy is reflected

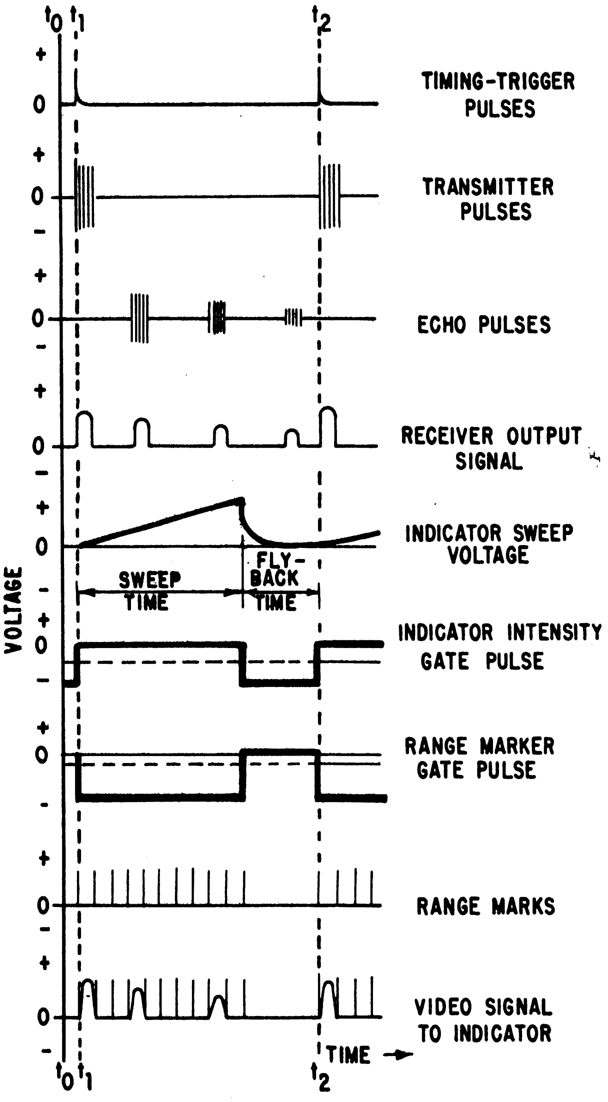

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Figure 11-1.—Time relationship of waveforms.

back to the antenna. Echo pulses from three reflecting targets at different ranges are illustrated in the part of figure 11-1 labeled "echo pulses." The corresponding receiver output signal is also shown.

The initial and final pulses in the receiver output signal are caused by the energy that leaks through the transmit-receive (TR) device when a pulse is being transmitted.

The indicator sweep voltage (fig. 11-1) is initiated at the same time that the transmitter is triggered. By delaying the timing-trigger pulse fed to the indicator sweep circuit, it is possible to initiate the indicator sweep after a pulse is transmitted. (It is also possible to initiate the indicator sweep before a pulse is transmitted.)

Note, in figure 11-1, that the positive indicator-intensity gate pulse (applied to the cathode-ray tube control grid) occurs during the indicator sweep time. As a result, the cathode-ray tube trace occurs only during the sweep time and is eliminated during the flyback (retrace) time. The negative range marker gate pulse also occurs during the indicator sweep time. This negative gate pulse is applied to a range marker generator, which produces a series of range marks.

The range marks are equally spaced and last only for the duration of the range marker gate pulse. When the range marks are combined (mixed) with the receiver output signal, the resulting video signal applied to the indicator may appear as shown in figure 11-1.

BASIC REQUIREMENTS

The basic timing circuit should meet three basic requirements:

1. It must be free running (astable)—since the timer is the heart of the radar, it must establish the zero time reference and the PRF.
2. It must be stable in frequency (PRF)—the PRF, or its reciprocal, the PRT, must not change between pulses for accurate ranging.
3. The frequency must be variable in steps—for the radar to operate on different ranges.

There are three basic circuits that can meet the above mentioned requirements. They are the sine-wave oscillator, single-swing blocking oscillator, and the master trigger multivibrator. Figure 11-2 shows the block diagrams and waveforms of these three timers used in externally synchronized radar systems. Note that in each case equally spaced timing-trigger pulses are produced. The repetition rate of each series of timing-trigger pulses is determined by the operating frequency of the associated master oscillator.

SINE-WAVE TIMER

In the sine-wave timer (fig. 11-2 (A)), a sine-wave oscillator is used for the basic timing device (master oscillator). The oscillator may be a Wien-bridge oscillator or a phase-shift oscillator. The oscillator output is applied

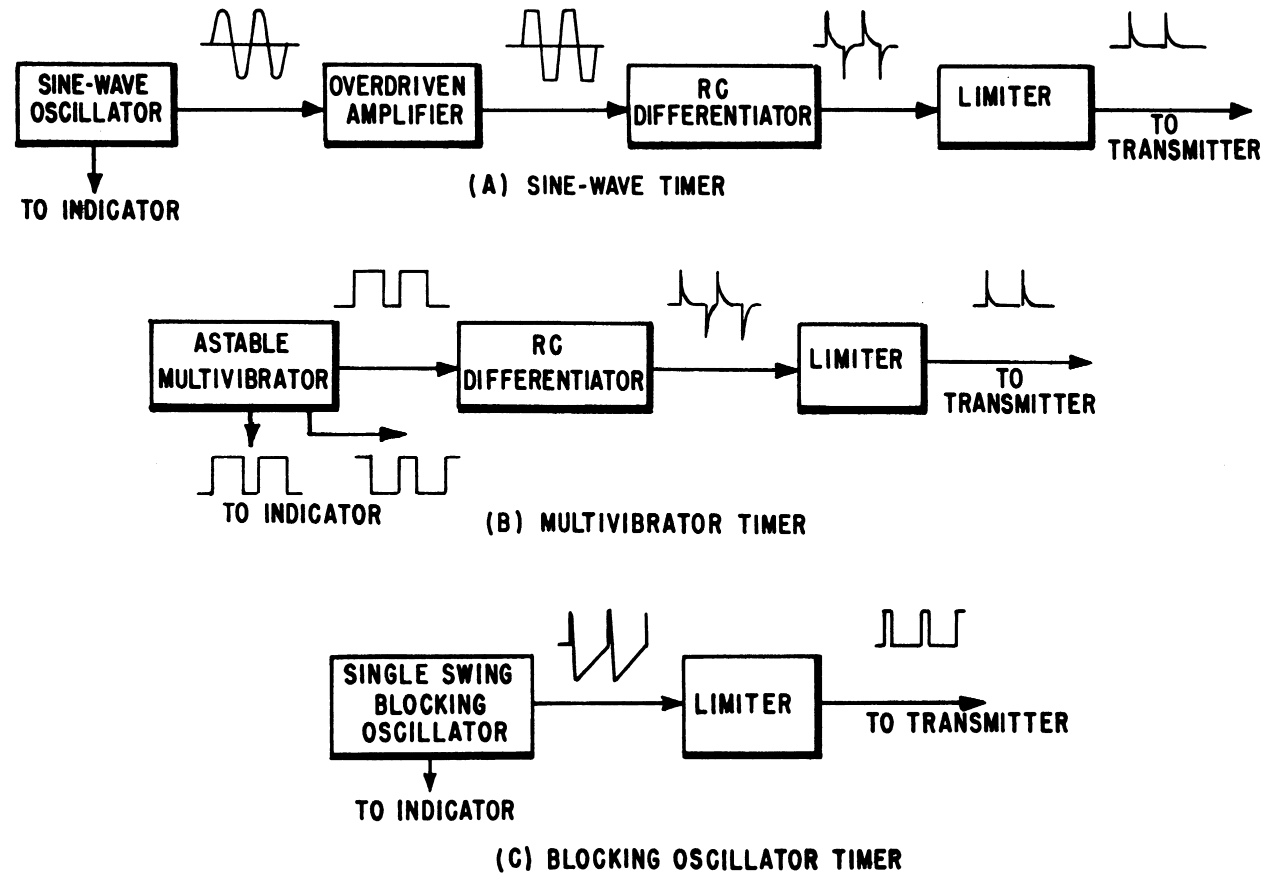

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Figure 11-2.—External timer block diagrams.

to both an overdriven amplifier and the radar indicator. The sine waves applied to the overdriven amplifier are converted into square waves. The square waves, in turn, are converted into positive and negative trigger pulses by means of a short-time-constant RC differentiator.

By means of a limiter, either the positive or negative trigger pulses from the RC differentiator can be removed, leaving trigger pulses of only one polarity. For example, the limiter of figure 11-2 (A) is a negative-lobe limiter; that is, the limiter removes the negative trigger pulses, and sends only positive trigger pulses to the radar transmitter.

One disadvantage of sine-wave timers is the large number of pules-shaping circuits required to produce the necessary timing-trigger pulses. Therefore, they are not normally found in modern weapons systems radar.

MULTIVIBRATOR TIMER

In a multivibrator timer, the master oscillator generally consists of an astable multivibrator. If the multivibrator is asymmetrical, as in figure 11-2 (B), it generates rectangular waves. If the multivibrator is symmetrical, it generates square waves. In either case, the timing trigger pulses are equally spaced after the limiter removes undesired positive or negative lobes.

The output of the astable multivibrator consists of two rectangular waves. (Remember, there are two tubes or transistors in an astable multivibrator; the two plate or collector output voltages are equal in amplitude, but 180° out of phase.) One set of rectangular pulses is applied to the RC differentiator and converted into positive and negative trigger pulses.

As in the sine-wave timer, the negative trigger pulses can be removed by means of a negative-lobe limiter. Both sets of rectangular pulses from the astable multivibrator are applied to the indicator for the following purposes:

1. One set of pulses is used to intensify the cathode-ray tube electron beam for the duration of the sweep.
2. The other set of pulses is used to gate the range marker generator. As will be shown later, rectangular pulses can also be used to produce range steps.

BLOCKING-OSCILLATOR TIMER

In the blocking-oscillator timer (fig. 11-2 (C)), a free-running, single-swing blocking oscillator is generally used as the master oscillator. The advantage of the single-swing blocking oscillator is that it generates sharp trigger pulses directly. Timing-trigger pulses of only one polarity are obtained by means of a limiter.

Gate pulses for the indicator circuits are produced by applying the output of the blocking oscillator to a one-shot multivibrator or a phantastron. Crystal-controlled oscillators may be used when very stable operation is required at a particular frequency.

RANGE MARKERS

The accuracy of target-range data provided by a radar varies with the use of the radar. For example, a weapons systems radar operating in its search (or map) mode needs to be accurate only within a few percent of its maximum range. However, an intercept type radar operating in its track mode must supply range data that is accurate within a few yards.

In some applications of radar, the indicator sweep is calibrated by a transparent overlay with an engraved scale. This enables the operator to estimate the range of targets. In other applications, electronic range marks are supplied to the indicator. They appear as horizontal lines on a B-scope and as concentric circles on a PPI-scope. The distance between range marks is generally determined by the type of equipment and its mode of operation.

In weapons systems radar that requires extremely accurate target-range data, a movable range marker may be used. The range marker is obtained from a range marker generator and may be a movable range gate or range step. When a PPI-scope is used, a range circle of adjustable diameter is used to measure range accurately. In some cases, movement of the range marker is accomplished by turning a calibrated control, from which range readings are obtained. In other cases, the range marker may be used as a range gate for automatic range tracking. In this case there may be no direct range readout, or the readout may be a voltmeter calibrated in range and to which range voltage, equivalent to range marker position, is applied.

This discussion describes the operation of three types of range marker generators: the range gate generator; the range marker generator; and the range step generator. The range gate generator, used in conjunction with a blocking oscillator, generates a movable range gate. The range marker generator and the range step generator, used in conjunction with an astable multivibrator, generate fixed range marks and a movable range step, respectively.

Range Gate Generator

Figure 11-3 shows a simplified block diagram of a typical radar synchronizer that includes a range gate generator. The indicator is a B-scope with the range deflection voltages applied to the vertical plates. Scopes are discussed later in this chapter.

The PRF is controlled by a master oscillator, or multivibrator, whose output is coupled to a thyratron trigger. The output of the thyratron trigger is used to trigger the radar modulator and the B-scope sweep circuits, thus starting the transmitting pulse and the range sweep at the same instant.

The phantastron in the sweep circuits is a timing circuit that supplies a sweep sawtooth to the sweep amplifier. The width of the gate and sawtooth is dependent on the range selected by the operator.

The range gate circuit receives its input pulse from the trigger thyratron and generates a delayed range gate pulse. The delay of this pulse from t_0 is dependent on the position of the target in range when tracking or on the manual positioning of the range volts potentiometer by the operator when in the search mode. The range gate triggers the range strobe multivibrator, whose output is amplified and sent

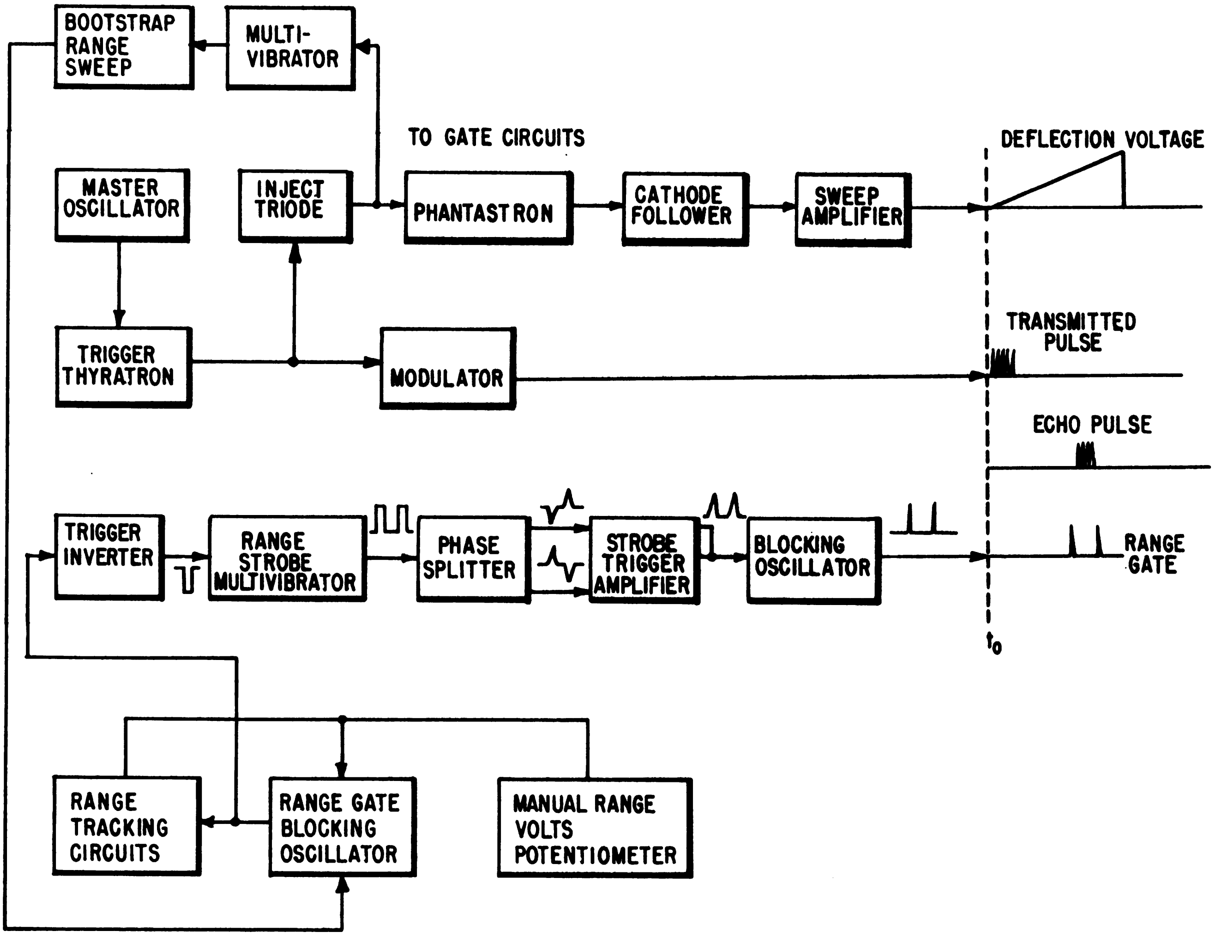

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Figure 11-3.—Synchronizer with range gate generator.

to the blocking oscillator that sharpens the pulses as shown in figure 11-3. This range gate is used to select the target to be tracked and, when in track mode, brightens the trace or brackets the target (depending on the system) to indicate which target is being tracked.

Range Marker Generator

Figure 11-4 is a block diagram of a typical range marker generator. This range marker generator consists of a ringing oscillator Q1611-Q1612, an emitter follower Q1613, a countdown multivibrator Q1616-Q1617, and a pulse forming amplifier Q1614. Generation of the marks commences at ringing oscillator Q1611-Q1612, which is excited into operation by the incoming trigger pulses, thereby producing a sinusoidal output which is synchronized to the trigger pulses. This sinusoidal output is applied to the emitter follower Q1613 which provides interstage buffering by isolating the ringing oscillator Q1612 from the countdown multivibrator Q1616-Q1617. The output coupling circuit of Q1613 shifts the average output level to zero (ground) and clips the negative going portions of the signal, thereby allowing only the positive half of each sine wave to reach the countdown multivibrator. The countdown multivibrator receives a high-frequency positive trigger corresponding to a fixed interval. The countdown multivibrator Q1616-A1617 is driven by this input to develop a negative pulse train, the period of which is controlled by the range marks

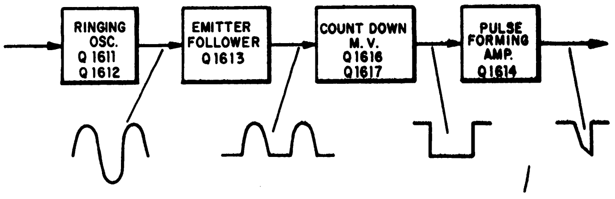

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Figure 11-4.—Range marker generator.

select switch. This negative output is applied to the pulse forming amplifier Q1614 where it is reshaped and passed on to a marker mixer.

The output of a range marker generator can be applied directly to one of the deflection plates of an A-scope. In this case, range marker pulses appear simultaneously with the radar echo signals, and permit estimation of target range. In B-scope and PPI-scope applications, the output of the range marker generator is applied to a video mixer. In this case, radar echo signals are combined with marker signals before being applied to the grid of the CRT.

Range Step Generator

Examine figure 11-5, the schematic diagram and waveforms of a typical range step generator. The range step generator consists of sawtooth voltage generator V1, negative clipper V2, and a limiting amplifier. Tube V2 is frequently referred to as a pickoff diode. The position of the range step along the indicator time base is controlled by potentiometer R3. When the range step coincides with the leading edge of a target echo pulse, the target range can be read directly from a calibrated range dial associated with R3.

Between times t_0 and t_1 (fig. 11-5 (B)), the grid of tube V1 is at ground potential (zero volts). As a result, VI conducts and the V1 plate voltage (e_{b1}) equals V1 plate-supply voltage E_{bb} minus the voltage drop across the plate-load resistor R1. The horizontal dashed line across the e_{b1} waveform indicates the voltage (E_{R3}, fig. 11-5 (A)) at the adjustable tap of potentiometer R3. Since e_{b1} is less than E_{R3} between times t_0 and t_1, the plate of the negative clipper V2 is less positive than the V2 cathode, and V2 does not conduct. Hence the V2 cathode voltage (e_k) equals E_{R3}, the voltage at the R3 tap.

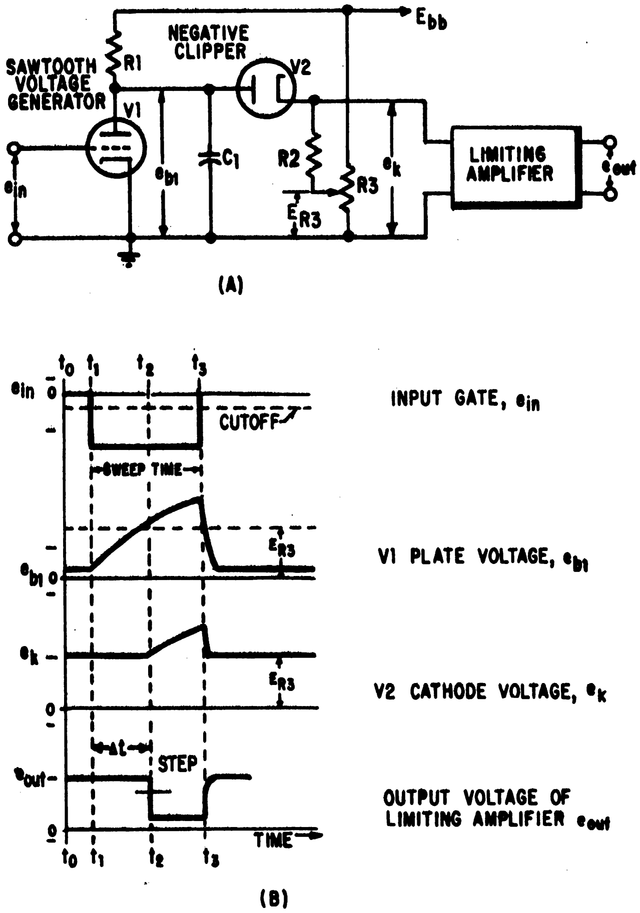

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Figure 11-5.—Range step generator with pickoff diode. (A) Schematic diagram; (B) waveforms.

Between times t_1 and t_3, the grid of tube V1 is driven below cutoff. As a result, V1 ceases to draw plate current. When no plate current flows in V1, capacitor C1 charges through V1 plate-load resistor R1, and the plate voltage of V1 (e_{b1}) rises exponentially toward V1 plate-supply voltage E_{bb}. At time t_2, e_{b1} exceeds E_{R3}, and tube V2 conducts. If the V2 plate resistance is small, the V2 cathode voltage (e_k) practically equals e_{b1} between times t_2 and t_3.

Following time t_3, the grid of tube V1 returns to ground potential, and V1 again conducts. As a result, capacitor C1 discharges through V1, and the V1 plate voltage decays exponentially toward its initial value. As soon as

e_{b1} becomes less than E_{R3}, tube V2 no longer conducts, and the V2 cathode voltage again equals E_{R3}.

When the e_k waveform is amplified and limited by the limiting amplifier, the amplifier output-voltage (e_{out}) waveform appears as in figure 11-5 (B). Note that a nearly vertical edge (step) appears in the e_{out} waveform the instant V2 begins to conduct (time t_2).

By varying the setting of the R3 tap, the instant at which V2 conducts can be varied. The position of the range step, therefore, can be controlled by adjusting the setting of R3. If a linear relationship is to be established between the delay of the step (Δt) and the voltage at the R3 tap (E_{R3}), the V1 sawtooth plate voltage must be linear.

The e_{out} waveform is applied to the vertical-deflection plates of a cathode-ray tube. Only the portion of the e_{out} waveform that occurs between times t_1 and t_3 is displayed on the cathode-ray tube screen. Remember, the indicator trace is blanked out during the flyback (retrace) time.

TRANSMITTER

The purpose of the transmitter is to develop high-power, high-frequency pulses of RF energy which are radiated into space by the antenna system.

Basically, the transmitter is an RF oscillator which is turned on and off in accordance with the signal received from the modulator. The oscillator is not normally controlled directly by the signal from the timer; instead, the timer triggers the modulator which, in turn, switches the transmitter on and off.

RADAR MODULATOR

The modulator controls the radar pulse width by means of a rectangular d-c pulse (modulator pulse) of the required duration and amplitude. The peak power of the transmitted (RF) pulse depends on the amplitude of the modulator pulse.

Figure 11-6 shows the waveforms of the trigger pulse applied by the timer to the modulator, the modulator pulse applied to the radar transmitter, and the transmitted RF pulse.

Note the following:

1. The modulator pulse is applied to the transmitter the instant the modulator receives the trigger pulse from the timer.

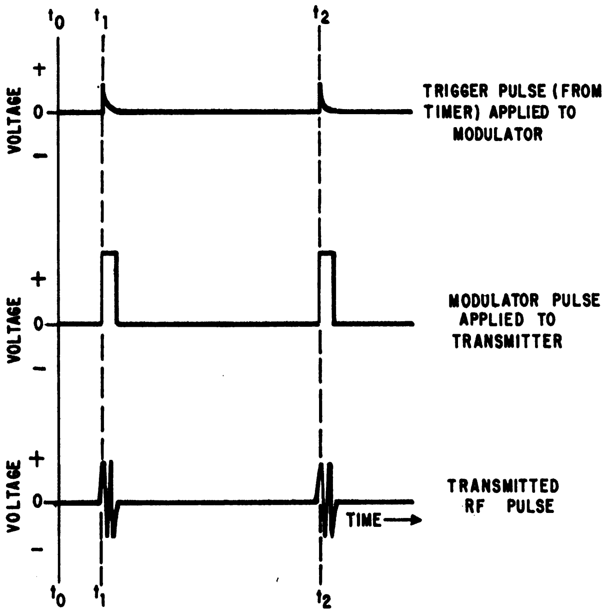

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Figure 11-6.—Radar pulse waveforms.

2. The modulator pulse is flat on top.
3. The modulator pulse has very steep leading and trailing edges.

Remember, for accurate determination of target range, the timing circuit must be triggered the instant the leading edge of the transmitted RF pulse leaves the transmitter. Thus, the trigger pulse that controls the operation of the modulator also synchronizes the cathode-ray tube sweep circuits and target range measuring circuits.

Magnetron oscillators are capable of generating RF pulses with very high peak power at frequencies ranging from 600 to 30,000 MHz. However, if its anode (plate) voltage changes, the magnetron oscillator shifts in frequency. Hence, the amplitude of the modulator (d-c) pulse must remain constant for the duration of the transmitted RF pulse. (That is, the modulator pulse must have a flat top.) The range of anode voltages over which a magnetron oscillates in the desired range is relatively small. In many cases the anode is at ground potential.

When a low voltage is applied to a magnetron, the magnetron produces a noise voltage output instead of oscillations. By entering the receiver, this noise can completely mask target echoes. If a modulator pulse builds up and decays slowly, noise is produced at the beginning and end of the pulse. Thus, for efficient radar operation, a magnetron requires a modulator pulse that has a flat top and steep leading and trailing edges; that is, the modulator pulse must perform the following:

1. Rise from zero to its maximum value almost instantaneously.
2. Remain at its maximum value for the duration of the transmitted RF pulse.
3. Fall from its maximum value to zero almost instantaneously.

In radars that require accurate range measurement, the transmitted RF pulse must have a steep leading edge. The leading edge of the echo is used for target-range measurement. If the leading edge of the echo is not steep and clearly defined, accurate range measurement is not possible. Remember, the leading and trailing edges of target echoes have the same shape as the leading and trailing edges of the transmitted RF pulse.

A transmitted RF pulse with a steep trailing edge is essential for detecting targets at short ranges. If the magnetron output voltage drops gradually from its maximum value to zero, it contributes very little to the usable energy of the transmitted RF pulse. Furthermore, part of the magnetron output voltage enters the receiver and obscures nearby targets.

There are two types of modulators—the line-pulsing modulator and the driver-hard-tube modulator. The line-pulsing modulator stores energy and forms pulses in the same circuit element. This element is usually the pulse forming network. The driver-hard-tube modulator forms the pulse in the driver; the pulse is then amplified and applied to the modulator. The hard-tube modulator has been replaced by the line-pulsed modulator. The reasons for this replacement are that the hard-tube modulator has lower efficiency, its circuits are more complex, higher power supply voltage is required, and it is more sensitive to voltage changes.

The line-pulsed modulator is easier to maintain because of its less complex circuitry and, for a given amount of power output, it is more compact and light. Since it is the principally used modulator in aviation radar, it is the only type that will be discussed at great length.

Figure 11-7 shows the basic components of a radar modulator. Note that the components of the radar modulator are as follows:

1. A power supply.
2. A storage element (a circuit element or network for storing energy).
3. A charging impedance (to control the charge time of the storage element and to prevent short-circuiting of the power supply during the modulator pulse).
4. A modulator switch (to discharge the energy stored by the storage element through the transmitter oscillator during the modulator pulse).

Figure 11-7 (A) shows the modulator switch open and the storage element charging. With the modulator switch open, the transmitter produces no power output, but the storage element stores a large amount of energy. Figure 11-7 (B) shows the modulator switch closed and the storage element discharging through the transmitter. The energy stored by the storage element is released in the form of a high-power, d-c modulator pulse. The transmitter converts the d-c modulator pulse to an RF pulse, which is radiated into space by the radar antenna. Thus, the modulator switch is closed for the duration of a transmitted RF pulse, but is open between pulses.

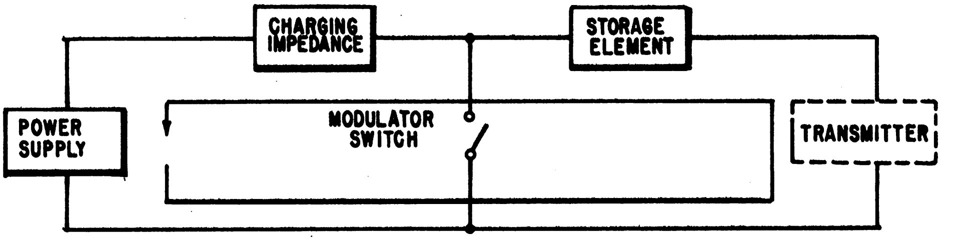
Many different kinds of components are used in radar modulators. The power supply generally produces a high-voltage output, either alternating or direct current. The charging impedance may be a resistor or an inductor. The storage element is generally a capacitor, an artificial transmission line, or a pulse-forming network. The modulator switch is usually an electron tube.

Modulator Storage Elements

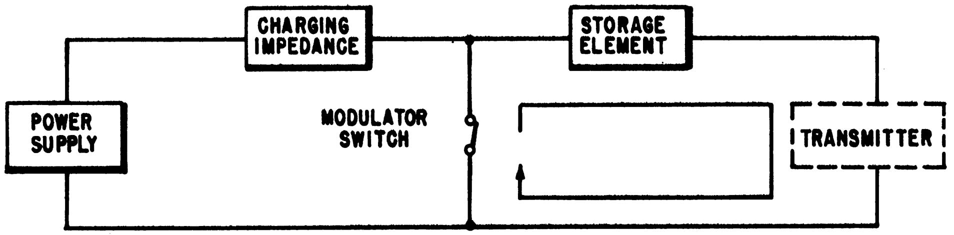
Capacitor storage elements are used only in modulators that have a d-c power supply and an electron-tube modulator switch.

The capacitor storage element is charged to a high voltage by the d-c power supply, and releases only a small part of its stored energy to the transmitter. The electron-tube modulator switch controls the charge and discharge of the capacitor storage element.

The artificial transmission line storage element (fig. 11-8 (A)) consists of identical capacitors (C) and inductors (L), arranged to simulate sections of a transmission line. The purposes of the artificial transmission line are to store energy when the modulator switch is open (between transmitted RF pulses), and to discharge and form a rectangular d-c pulse



(A) MODULATOR SWITCH OPEN — STORAGE ELEMENT CHARGING



(B) MODULATOR SWITCH CLOSED — STORAGE ELEMENT DISCHARGING

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Figure 11-7.—Basic radar modulator block diagram. (A) Modulator switch open; (B) modulator switch closed.

(modulator pulse) of the required duration when the modulator switch is closed.

The duration of the modulator pulse depends on the values of inductance and capacitance in each LC section of the artificial transmission line (fig. 11-8 (A)) and the number of LC sections used. Other arrangements of capacitors and inductors (pulse-forming networks) are very similar in operation to artificial transmission lines.

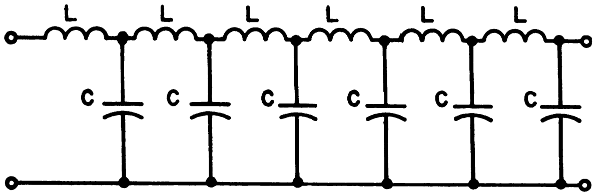
CAPACITOR.—Figure 11-9 (A) is the schematic diagram of a modulator that uses a single capacitor (C1) as its storage element. The charge and discharge of C1 is controlled by triode V1, which is a high-vacuum switch tube. V1 is normally held below cutoff by a negative d-c bias applied to its grid.

When a positive trigger pulse (from the radar timer) is applied to the V1 grid, V1 conducts for the duration of the trigger pulse. When V1 is cut off, storage capacitor C1 charges through the series circuit consisting of the d-c power supply, charging impedance Z1, and charging diode V2. The low voltage across V2 effectively prevents the RF oscillator from operating.

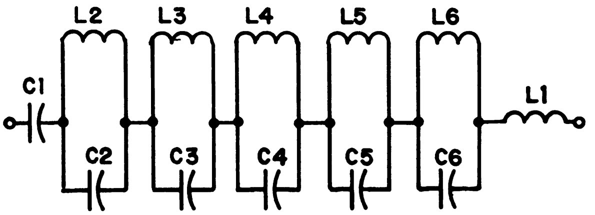
When a positive trigger pulse is applied to the grid of V1, V1 suddenly conducts, and C1 discharges. The discharge path (fig. 11-9 (A)) is a series circuit consisting of switch tube V1 and the RF oscillator. Note that discharge current I2 is opposite in direction to charge current I1. Since charging diode V2 can conduct in only one direction (from cathode to plate), V2 remains cut off during the modulator pulse. Thus discharge current I2 flows through the RF oscillator, and an RF pulse is generated by the oscillator.

During the modulator pulse, storage capacitor C1 discharges, and the C1 voltage decreases. Since the C1 voltage (modulator pulse) is applied to the RF oscillator, the frequency of the oscillator changes if there is any significant change in the C1 voltage. To keep the C1 voltage practically constant, C1 must have a large capacitance. Thus, only a small fraction of the charge is removed from C1 during the modulator pulse, and the C1 voltage remains practically constant.

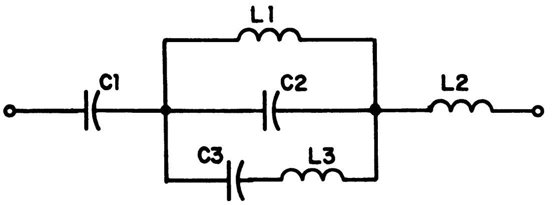
The switch tube (V1) starts and stops the modulator pulse. Thus, the width (duration) of the modulator pulse depends on the width of the



(A) ARTIFICIAL TRANSMISSION LINE



(B) PULSE—FORMING NETWORK



(C) PULSE—FORMING NETWORK

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Figure 11-8.—Types of modulator storage elements.

trigger pulse applied to the V1 grid. The pulse repetition rate depends on the rate at which trigger pulses are applied to the V1 grid. To obtain a modulator pulse with nearly vertical sides (a d-c rectangular pulse), the trigger pulse must also have nearly vertical sides. Modulators that use capacitor storage elements and high-vacuum electron tubes as switches have the following advantages:

1. The pusle repetition rates can be varied over relatively wide limits.
2. The pulse width can also be varied over relatively wide limits.

ARTIFICIAL TRANSMISSION LINE.—Examine figure 11-9 (B)), which shows a radar modulator that uses an artificial transmission line as its storage element. A switch (modulator switch) controls the pulse repetition rate. When the modulator switch is open (between modulator pulses), the transmission line charges.

The charge path includes the primary of pulse transformer T1, the d-c power supply, and charging impedance Z1. When the modulator switch is closed, the transmission line discharges through the series circuit consisting of the modulator switch and the primary of pulse transformer T1.

The artificial transmission line is effectively an open circuit at its output end. Thus, when the voltage wave reaches the output end of the line, it is reflected. As the reflected wave propagates from the output end toward the input end of the line, it completely discharges each section of the line. When the reflected wave reaches the input end of the line, the line is completely discharged, and the modulator pulse ceases abruptly. If the oscillator and pulse transformer circuit impedance is properly matched to the line impedance, then the voltage pulse that appears across the T1 primary is one-half the voltage to which the line was charged initially.

The width of the pulse generated by an artificial transmission line depends on the time required for a voltage wave to travel from the input end to the output end of the line and back. Thus, the pulse width depends on the velocity of propagation along the line (determined by the inductance and capacitance of each section of the line) and the number of line sections (the length of the line).

PULSE-FORMING NETWORKS.—A pulse-forming network is similar to an artificial transmission line in that it stores energy between pulses and produces an almost rectangular pulse. The pulse-forming network (fig. 11-8 (B)) consists of inductors and capacitors arranged so that they approximate the behavior of an artificial transmission line.

Each capacitor in the artificial transmission line (fig. 11-8 (A)) must carry the high voltage required for the modulator pulse. Since each capacitor must be insulated for this high voltage, an artificial transmission line consisting of many sections is bulky and cumbersome. The pulse-forming network (fig. 11-8 (B)) can carry high voltage but does not require bulky insulation on all of its capacitors. Only series capacitor C1 must be insulated for high voltage. Since the other capacitors are in parallel with the corresponding inductors, the modulator pulse voltage divides nearly equally among them. Thus, except for C1, the elements of the pulse-forming network are relatively small.

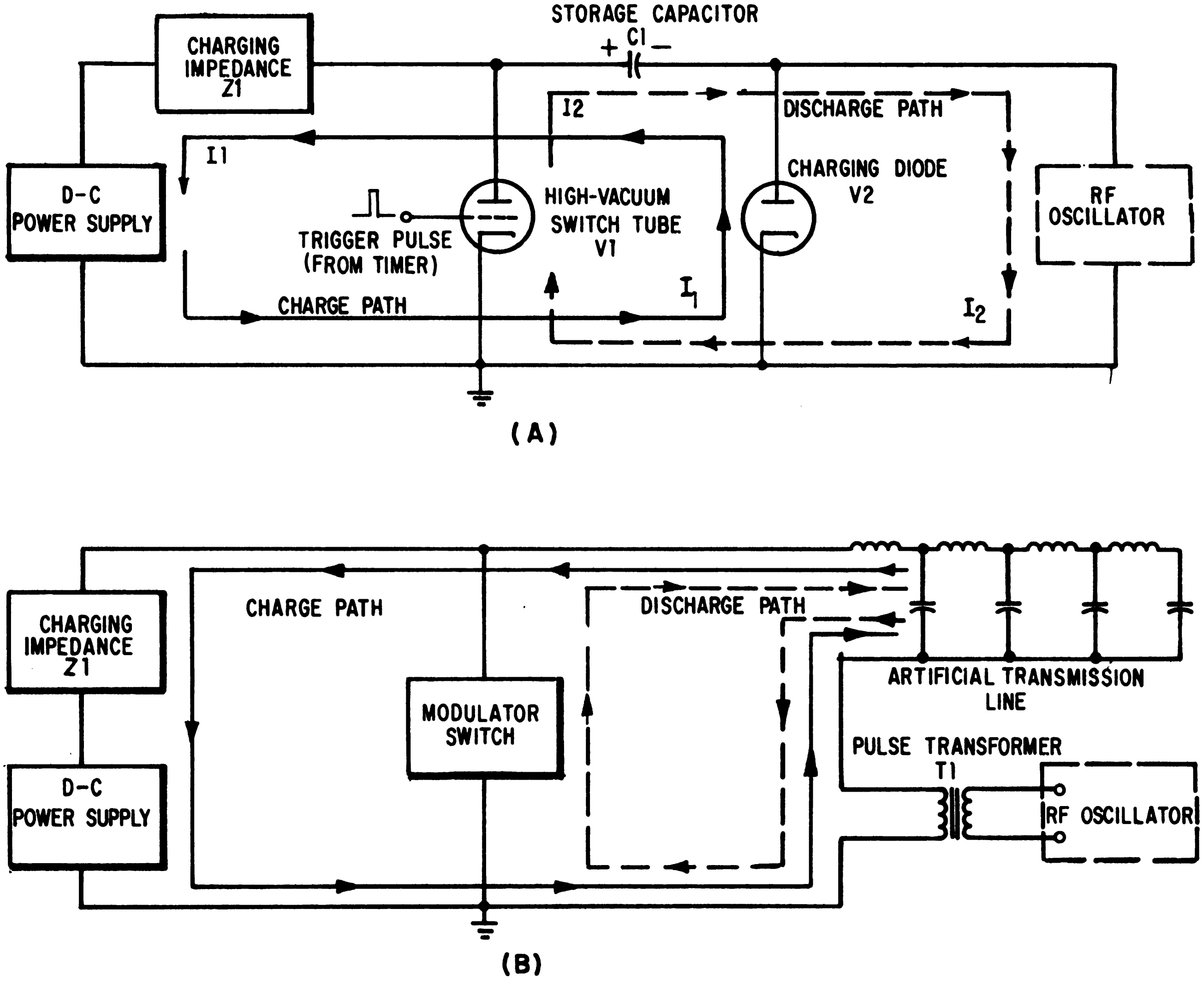

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Figure 11-9.—Applications of basic modulator elements. (A) Single capacitor; (B) artificial transmission line.

Pulse-forming networks are often insulated by immersing each circuit element in oil. The network is usually enclosed in a metal box, on which the pulse length, characteristic impedance, and safe operating voltage of the network are marked. If one element in such a network fails, the entire network must be replaced.

Switching Devices

The voltage stored in a storage-element capacitor, artificial transmission line, or pulse-forming network must be discharged through a switching device. The switching device conducts for the duration of the modulator pulse, and is open-circuited between pulses. Thus, the modulator switch must perform the following functions:

1. Close suddenly, and reach full conduction in a samll fraction of a microsecond.
2. Conduct large currents (tens or hundreds of amperes), and withstand large voltages (thousands of volts).
3. Cease conducting (become an open circuit) with the same speed that it starts to conduct.
4. Consume only a very small fraction of the power that passes through it.

These requirements are met best by the thyratron tube (gas-filled).

The thyratron, normally held below cutoff by a negative grid voltage, conducts when a positive trigger pulse is applied to its grid. Once fired, the thyratron continues to conduct as long as the storage element (artificial transmission line or pulse-forming network) is discharging.

During discharge of the storage element, the gas in the thyratron is highly ionized. While the storage element discharges, the plate-to-cathode resistance of the thyratron is practically zero. When the storage element is completely discharged, current ceases to flow through the thyratron and the gases become deionized. Thus, the negative grid bias regains control, and the thyratron is cut off (the modulator switch opens).

Most radar modulators use a high-voltage, d-c power supply. Typical d-c power supplies for radar modulators use a half-wave rectifier, a full-wave rectifier, or a bridge rectifier.

The modulator charging impedance (fig. 11-10 (A)) prevents the d-c power supply from becoming short-circuited when the modulator switch closes. When the modulator switch is open, the charging impedance also controls the rate at which the storage element charges. When the charging impedance is large, the storage element charges slowly. When the charging impedance is small, the storage element charges rapidly.

Many different kinds of charging impedance and charging circuits are used in radar modulators. The type of charging impedance and charging circuit used depends on the following:

1. The type of power supply (a.c. or d.c.).
2. The type of storage element.
3. The modulator pulse voltage required.
4. The pulse repetition rate.
5. The frequency of the available a-c supply voltage.

Most radar modulators charge very slowly compared with the rate at which they discharge. (The interval between modulator pulses is much longer than the pulse width.) Because the charging current is relatively small and changes very slowly, inductances in a modulator storage element have negligible effect on charging. Thus, all modulator storage elements can be represented as a capacitor during their charging interval, as in figure 11-10 (B).

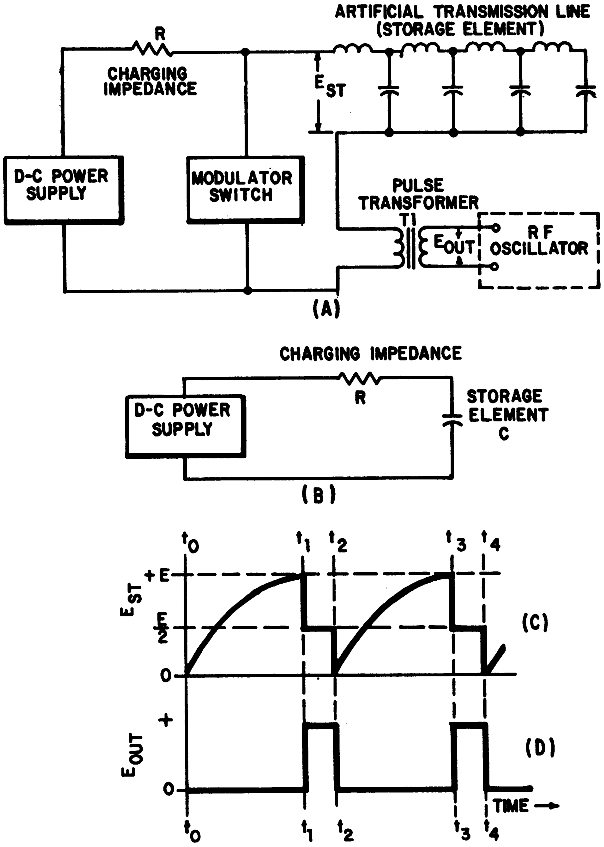

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Figure 11-10.—Radar modulator with resistance charging, (A) Schematic diagram; (B) equivalent charge circuit; (C) storage element voltage (E_{st}) waveform; (D) T1 secondary voltage (E_{out}) waveform.

RESISTANCE CHARGING.—In figure 11-10 (B), the equivalent charging circuit of the radar modulator, note that a capacitor C represents the storage element (artificial transmission line) of the modulator. A resistor R represents the charging impedance. When the modulator switch is open, the storage element charges, along a typical RC charge curve, to a maximum voltage, E (time interval $t_0 - t_1$, fig. 11-10 (C)).

When the modulator switch is closed (time t_1), the storage-element voltage (E_{st}) decreases to E/2. (Remember, if an artificial transmission line or pulse-forming network is charged to a maximum voltage, E, and a matching impedance load is suddenly connected across the line, the line voltage decreases instantly to E/2.) Voltage E_{st} remains at E/2 for the duration of the modulator pulse (time interval $t_1 - t_2$). At the end of the modulator pulse (time t_2), voltage E_{st} suddenly decreases to zero. Shortly afterwards, the modulator switch opens, and a new charging cycle begins.

With the storage element charging (time interval $T_0 - t_1$), the change in current through the pulse-transformer primary (T_1, fig. 11-10 (A)) is too slow to produce an output voltage. Thus, the T1 secondary voltage (E_{out}, fig. 11-10 (D)) is zero. When the modulator switch closes (time t_1), the rapid decrease in storage-element voltage (E_{st}, fig. 11-10 (C)) appears across the T1 primary and induces a high voltage in the T1 secondary.

During the modulator pulse (time interval $t_1 - t_2$), voltage E_{out} remains constant. At the end of the pulse (time t_2), T1 secondary voltage decreases suddenly to zero. Thus, pulse transformer T1 converts the rapidly changing storage-element voltage to a steep, high-voltage pulse.

RESONANCE CHARGING.—If the charging resistor is replaced by an inductor, the charging circuit becomes series resonant. When a d-c voltage is applied to a series-resonant circuit (fig. 11-11 (A)), capacitor C begins charging through inductance L. When E_c approaches the applied d-c voltage E, the magnetic lines of force due to current flow through L begin collapsing and sustain the charging current. In this way capacitor voltage E_c rises to its maximum value, which is twice the applied d-c voltage, E. (Due to circuit losses in actual practice, this voltage is approximately 1.9E.) The capacitor voltage then oscillates at the resonant frequency of the LC circuit. These oscillations gradually decay until E_c becomes constant, and equals E, the applied d-c voltage. This is called d-c resonance charging.

D-c resonance charging is used only when the pulse repetition period corresponds to the resonant frequency of the LC circuit. For example, with d-c resonance charging, the modulator switch closes at the instant the capacitor voltage reaches its maximum value (time t_1, fig. 11-11 (A)). The advantage of d-c resonance charging is that it permits the storage element to be charged to a voltage twice the d-c power-supply voltage. Its disadvantage is that the pulse repetition rate is fixed by the resonant frequency of the LC charging circuit.

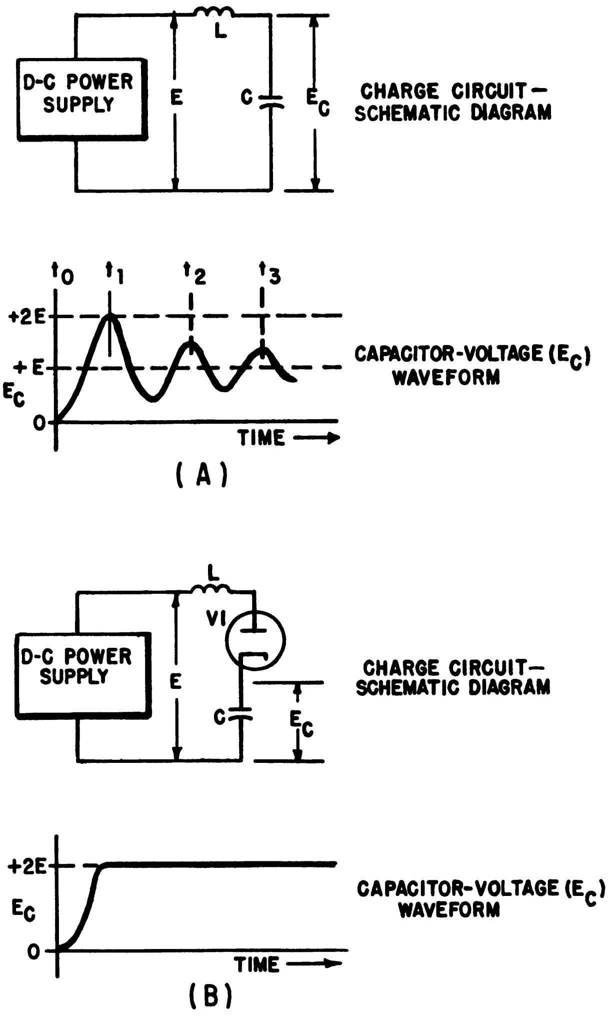
D-C POWER SUPPLY
L
E
C
E_C
CHARGE CIRCUIT—SCHEMATIC DIAGRAM
t_0
t_1
t_2
t_3
+2E
+E
E_C
0
TIME
CAPACITOR-VOLTAGE (E_C) WAVEFORM
(A)
D-C POWER SUPPLY
L
V1
E
C
E_C
CHARGE CIRCUIT—SCHEMATIC DIAGRAM
+2E
E_C
0
TIME
CAPACITOR-VOLTAGE (E_C) WAVEFORM
(B)

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Figure 11-11.—(A) D-c resonance charging; (B) resonance charging with a diode.

Addition of a diode to the resonant charging circuit permits the storage element to charge to a d-c voltage twice the applied d-c voltage, and as a result, E_c increases to its maximum value (2E), and then remains constant. Look at figure 11-11 (B), the schematic diagram and the capacitor voltage (E_c) waveform of a resonant charging circuit that uses a diode. Note that diode V1 is connected in series with the charging impedance (inductor L) and the storage element (represented by capacitor C). Since V1 can conduct in only one direction, capacitor C is charged through the d-c power supply. The storage element (C) can be discharged at any time after E_c reaches its maximum value. Thus, the pulse repetition rate can be varied over a wide range.

MAGNETRON OSCILLATOR

Figure 11-12 shows a typical microwave-radar transmitting system consisting of a magnetron oscillator, a waveguide transmission line, and a microwave-radar antenna. Note that the magnetron oscillator is coupled to the waveguide.

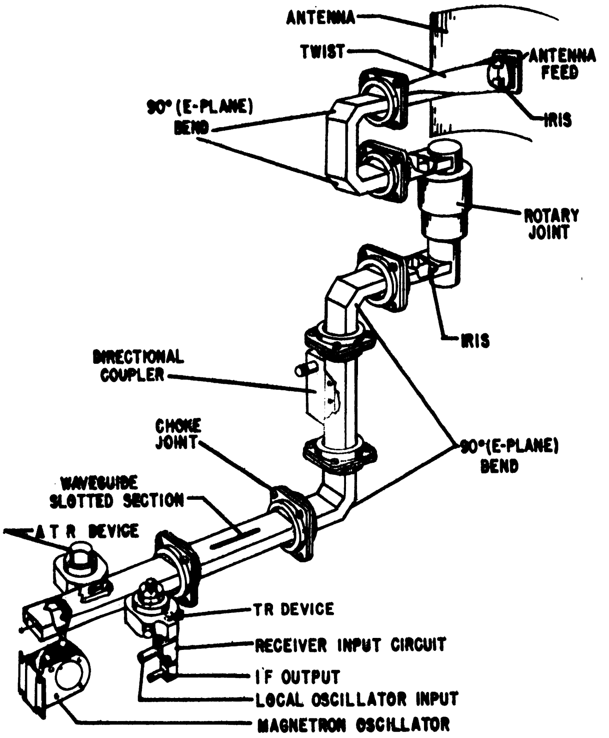

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Figure 11-12.—Microwave-radar transmitting system.

Many different waveguide circuit elements are connected between the magnetron and the antenna: choke joints, twists, bends, directional couplers, etc. Fundamentals of waveguides are presented in Basic Electronics.

The magnetron is a high-power, microwave oscillator used in almost every microwave radar. Efficient high-power magnetrons, developed during the early part of World War II, made long-range microwave radar possible. The magnetron is essentially a diode equipped with a powerful magnet. The magnetic field of the magnet influences the flow of electrons between the cathode and anode of the magnetron.

Magnetrons are used as high-power oscillators in the microwave frequency range of approximately 1,000 to 30,000 MHz. The peak power ratings of magnetrons range from a few kilowatts to several million watts (megawatts). However, the average power ratings are much lower, and vary from a few watts to several kilowatts.

Figure 11-13 (A) is a cutaway view of a magnetron of the type currently used in airborne radar.

Different types of magnetrons have different types of anode blocks. The type shown in figure 11-13 (A) is called a hole-and-slot anode block because each cavity resonator is formed by a hole and slot. Other types of magnetrons use radial vanes (specially shaped slots) as resonant cavities. For example, the rising-sun anode block consists of alternate deep and shallow slots.

Many of the magnetrons used in modern equipment are tunable, the most common of which uses slugs inserted in the anode block holes for varying the inductive reactance of the cavity, thus changing the resonant frequency.

Because their operation depends on so many factors, magnetrons require special precautions. Magnetron magnets should never be struck sharply. When struck, these magnets may lose some of their magnetization.

Modulating signals of many thousand volts are applied to the magnetron cathode. Thus, large and heavy glass posts are used to insulate the filament and cathode leads from the anode block.

After generation in the magnetron, the radar pulses are sent to the antenna via a system of waveguides and couplers as shown in figure 11-12. The detailed characteristics of the antenna system and advanced antenna theory are beyond the scope of this manual; basic fundamentals concerning antennas and wave propagation should be reviewed in Basic Electronics.

RECEIVER

Radar systems generally use high-gain, low-noise, superheterodyne receivers with RF amplifier or crystal mixer input stages. In the microwave bands, superheterodyne receivers, with RF amplifiers generate an undesirable amount of noise; therefore, crystal mixers are used at these frequencies.

Some special tubes have been developed that easily provide amplification of small signals at

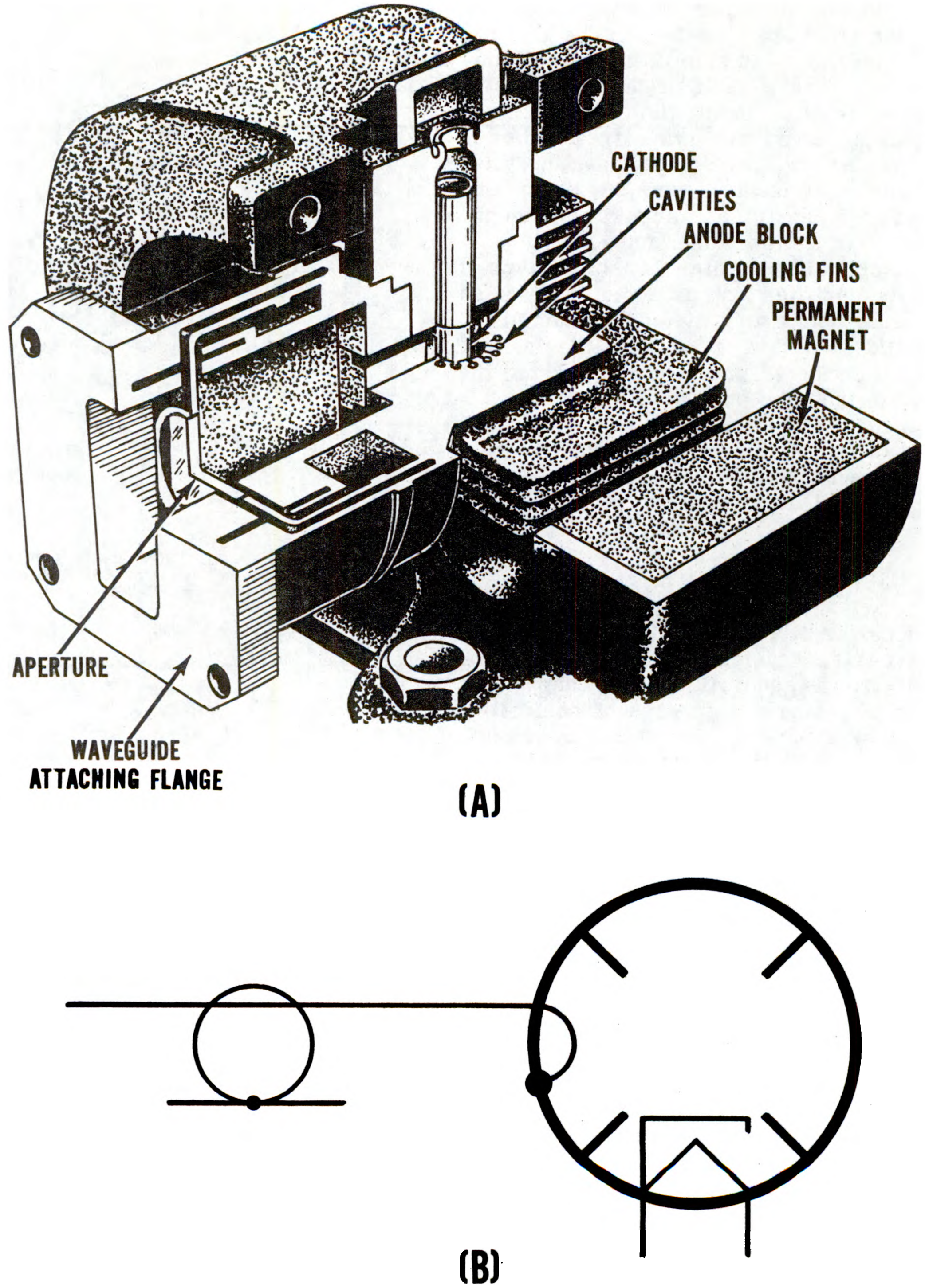

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Figure 11-13.—(A) Typical magnetron, cutaway view; (B) graphical symbol (resonant type with coaxial output).

these frequencies. Two of these are the klystron and the traveling wave tube. The klystron is not very useful as an amplifier of small signals because the tube itself produces excessive noise; however, it is finding wide application as a power amplifier at microwave frequencies in airborne radar systems. The traveling wave tube, on the other hand, is very useful for amplifying small signals at microwave frequencies because of its low noise factor.

The parametric amplifier is another type of microwave amplifier that produces little noise to the signal being amplified. This amplifier uses a solid state device as its basic element. The amplification is produced by varying the reactance of the solid state device.

The theory of operation of these amplifiers is beyond the scope of this manual and has only been mentioned to help you to realize that other means of amplification do exist.

LOCAL OSCILLATOR

The local oscillator used in practically all microwave-radar systems is a klystron. The reflex klystron is generally used because of its simplicity of tuning and its ease of controlling frequency by means of its repeller voltage. Figure 11-14 (A) is the cutaway view of a typical integral-cavity, reflex-klystron oscillator. Figure 11-14 (B) shows typical tuning curves for the klystron oscillator. In the reflex klystron, the resonant frequency of the resonator cavity is changed by adjusting a tuning strut. The tuning strut deforms the cavity, thus changing the resonant frequency of the cavity.

The electron gun in a klystron accelerates electrons to a high velocity, and beams them through the grids of the klystron resonator cavity. RF voltages across the cavity grids change the electron-stream velocity sinusoidally. In the region beyond the cavity grids, the electron stream is slowed down, stopped, and returned toward the cavity grids by the negative repeller voltage.

Because electrons enter the reflection region at different velocities, the electrons travel in different paths. As a result, the reflected electrons return to the cavity-grid region in bunches. If the reflected electron bunches have the proper phase with respect to the RF voltage across the cavity grids, power is delivered to the resonator cavity and cavity oscillations are reinforced.

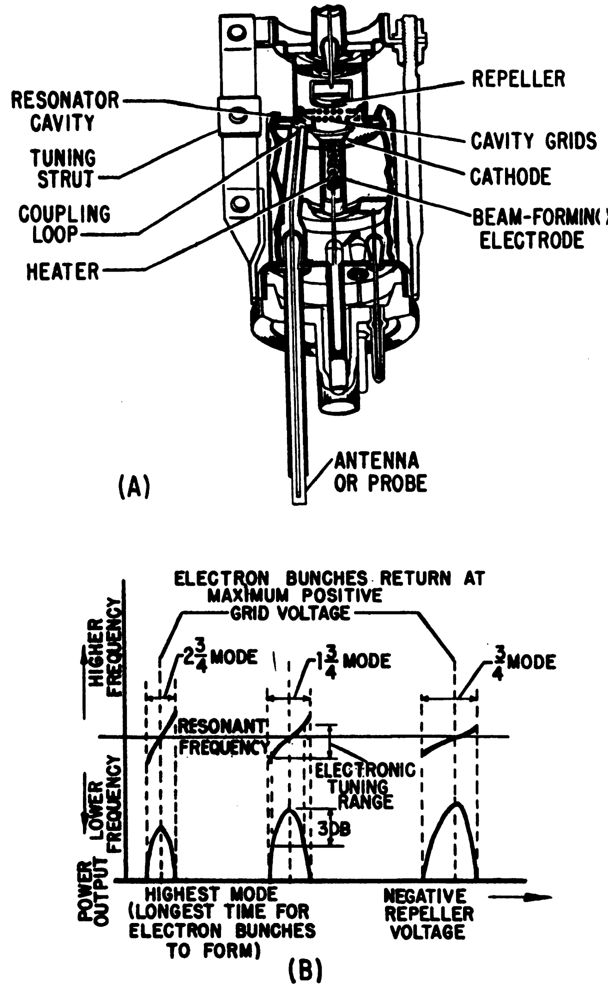

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Figure 11-14.—Typical reflex-klystron oscillator. (A) Cutaway view; (B) tuning curves.

Figure 11-14 (B) shows the variation of klystron power output and frequency with changes in repeller voltage. Note that there are a number of repeller voltages, called voltage modes, at which power output is produced. These voltage modes correspond to different reflection points of the electron stream, and different numbers of RF cycles that occur before the reflected electrons return to the cavity grids. Note also that, in each mode, the repeller voltage produces maximum power output at the same resonant frequency.

As the repeller voltage is changed in each mode, the resonant frequency of the klystron also changes. A higher repeller voltage produces a higher resonant frequency; a lower (less negative) repeller voltage produces a lower resonant frequency. This change of klystron resonant frequency with repeller voltage is one of the important reasons for using klystrons in radar local oscillators.

The change of klystron resonant frequency with repeller voltage permits the use of automatic frequency control (AFC) with the klystron local oscillator. By means of AFC circuits in the radar receiver, the klystron local oscillator keeps the receiver tuned to produce the correct IF frequency at all times. Because klystron frequency is controlled by repeller voltage, the repeller supply voltage must be free of ripple and carefully regulated.

Klystron oscillators require two d-c voltages for their operation—an accelerator voltage and a repeller voltage. In most klystron tubes, the accelerator electrodes are the grids of the klystron cavity. These electrodes are usually maintained at ground potential since they are connected to the shell of the klystron. In some cases, however, the accelerator voltage is applied to both the cavity grids and the klystron shell, resulting in high voltages on the klystron shell.

When the cavity grids (accelerator electrodes) are maintained at ground potential, negative voltage must be applied to the cathode to obtain the required electron-beam accelerating voltage. In addition, the repeller voltage must be negative with respect to the cavity grids, and larger than the cathode voltage. When the cathode of a klystron is at ground potential, the repeller must be negative, and the cavity grids (and the klystron shell) must operate at a large positive voltage.

The klystron provides a local-oscillator signal to convert the received RF signal to an IF signal. Thus, the klystron output must be applied to the mixer. Probe coupling is usually employed.

Observe the antenna (probe), in figure 11-14 (A), that extends below the klystron base pins. The probe is located so that it will pass through an enlarged hole in a standard octal socket. The probe is a small-diameter coaxial line with its center conductor extending beyond its outer conductor. The coaxial line is coupled to the resonator cavity by a fixed loop.

The klystron is coupled to the receiver input circuit by inserting the probe (or antenna) into the receiver waveguide in such a way that both the received signal and the local-oscillator signal are applied to the mixer. When the klystron probe is inserted into the broad face of the waveguide, the voltage between the probe center conductor and outer conductor causes two results. Voltages are induced in the waveguide, and the oscillator delivers power to the mixer.

The thermal tuned klystron (fig. 11-15) is frequently found in modern equipments. The main difference between it and the one already discussed (fig. 11-14) is the method of tuning. Thermal tuning allows accurate remote control of the coarse tuning. The major control is applied to the cavity, which is tuned by the triode amplifier. Although the repeller is also controlled, there is a blocking capacitor between the repeller and the source of control. This limits repeller action to short-term variations. The d-c repeller voltage is obtained from a divider between -250 volts and ground.

Heat resulting from the triode conduction lowers the oscillator frequency by changing the size of the cavity. When the heat is off, the oscillator rises in frequency. With no output from the mixer, conduction of the triode is controlled by a positive pulse from a heat control multivibrator that gates the triode every 5 seconds. When an IF signal is present, the AFC circuit locks on and the heat multivibrator switches at 120 Hz maintaining the oscillator frequency 30 MHz below the transmitted frequency.

CRYSTAL MIXER

A crystal mixer is one of the most important parts of a radar receiver. Remember, mixers in superheterodyne receivers combine RF and local-oscillator signals to produce sum and difference frequencies. Most receivers use the difference-frequency output of the mixer for amplification in the IF amplifier. In radar receivers, the mixer consists of either one or two crystal diodes.

Figure 11-16 is a cutaway view of a typical mounting arrangement for a waveguide crystal mixer. The crystal at the left (AFC crystal) is used for automatic frequency control of the local oscillator. (The operation of radar AFC circuits is described later.) The crystal at the right (receiver crystal) combines the RF input and local-oscillator output signals to produce the required IF signal.

In the waveguide crystal mixer, one end of the receiver crystal is connected to the top of the waveguide. The other end of the receiver

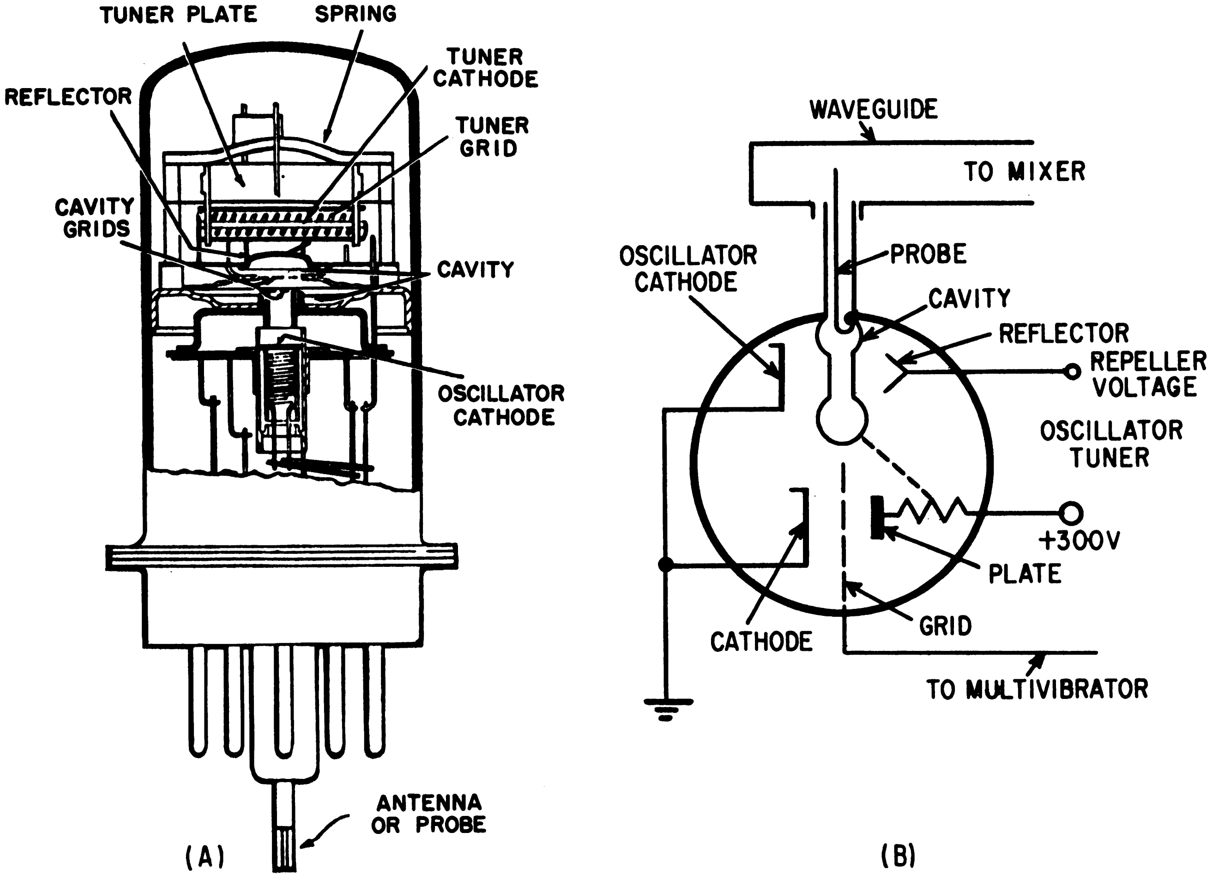

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Figure 11-15.—Thermal tuned klystron. (A) Curaway view; (B) schematic diagram.

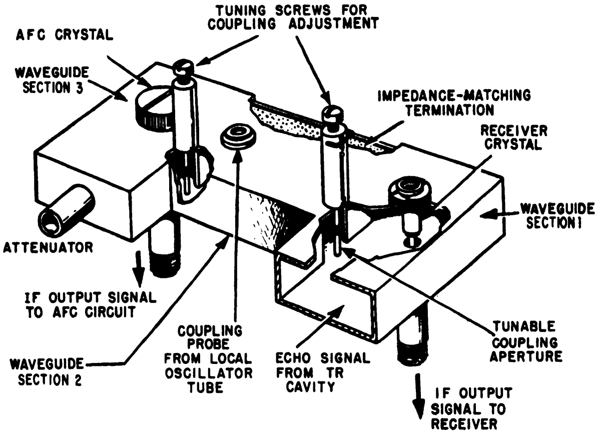
crystal is connected to the center conductor of a coaxial line, which feeds the receiver IF amplifier. The local-oscillator output signal is fed to waveguide section 2 by a coupling probe inserted through the top face of the waveguide.

The local-oscillator output signal is coupled to waveguide section 1 through a tunable coupling aperture. When this aperture is tuned to the local-oscillator output frequency, the local-oscillator output signal passes into waveguide section 1, which contains the receiver crystal. The RF input signal that enters waveguide section 1 is prevented, by the tunable coupling aperature, from entering waveguide section 2.

Crystals in a waveguide crystal mixer are held in place by a threaded cap, which provides a d-c ground return for the crystal. To replace a crystal, unscrew the cap and remote the crystal from its holder. Between the receiver crystal and the IF output line (to the receiver), an RF choke prevents RF signals from appearing across the IF output circuit.

IF AMPLIFIERS

Radar IF amplifiers require high gain to amplify the input signal to the level required to operate the detector. Many different circuit arrangements are used to obtain the required gain. Besides having high gain, the radar IF amplifier must have sufficient bandwidth to pass all of the important sidebands of the IF signal. Remember that the shorter the radar pulse, the wider the required IF bandwidth.


AFC CRYSTAL
TUNING SCREWS FOR COUPLING ADJUSTMENT
WAVEGUIDE SECTION 3
IMPEDANCE-MATCHING TERMINATION
RECEIVER CRYSTAL
WAVEGUIDE SECTION 1
ATTENUATOR
IF OUTPUT SIGNAL TO AFC CIRCUIT
COUPLING PROBE FROM LOCAL OSCILLATOR TUBE
ECHO SIGNAL FROM TR CAVITY
TUNABLE COUPLING APERTURE
WAVEGUIDE SECTION 2
IF OUTPUT SIGNAL TO RECEIVER

AQ.450

Figure 11-16.—Waveguide crystal mixer.

The longer the pulse, the narrower the allowable bandwidth.

High gain and wide bandwidth cannot be obtained in a single-stage amplifier. High amplifier gain is obtained by using a large value of load resistance. A parallel-resonant circuit with a high value of Q (narrow-bandwidth resonance curve) has a large value of load resistance. To obtain a wide-bandwidth (low Q) resonance curve, a low value of load resistance must be connected across the resonant circuit. However, this results in a lower voltage for the IF amplifier stage.

The gain of an IF amplifier, in which load resistance is usually much lower than plate resistance, is directly proportional to the amplifier load resistance. That is, the greater the load resistance, the greater the gain. The bandwidth of an IF amplifier is inversely proportional to the amplifier load resistance. In other words, the greater the load resistance, the narrower the IF bandwidth.

Thus, for a given IF amplifier tube, the product of gain and bandwidth is constant and is called the gain-bandwidth product. The value of this product is important in servicing IF amplifiers. When you replace a plate-load resistor with a resistor of higher value, the IF bandwidth decreases, and IF amplifier gain increases.

Single Tuning

Figure 11-17 (A) is a schematic diagram of a single-tuned, interstage coupling circuit frequently used in radar IF amplifiers. Fundamentals of amplifier circuits, tuning methods, and coupling methods may be reviewed in Basic Electronics. Analysis of amplifier circuit parameters for calculation of gain and bandwidth, as well as typical response curves, are also discussed in Basic Electronics.

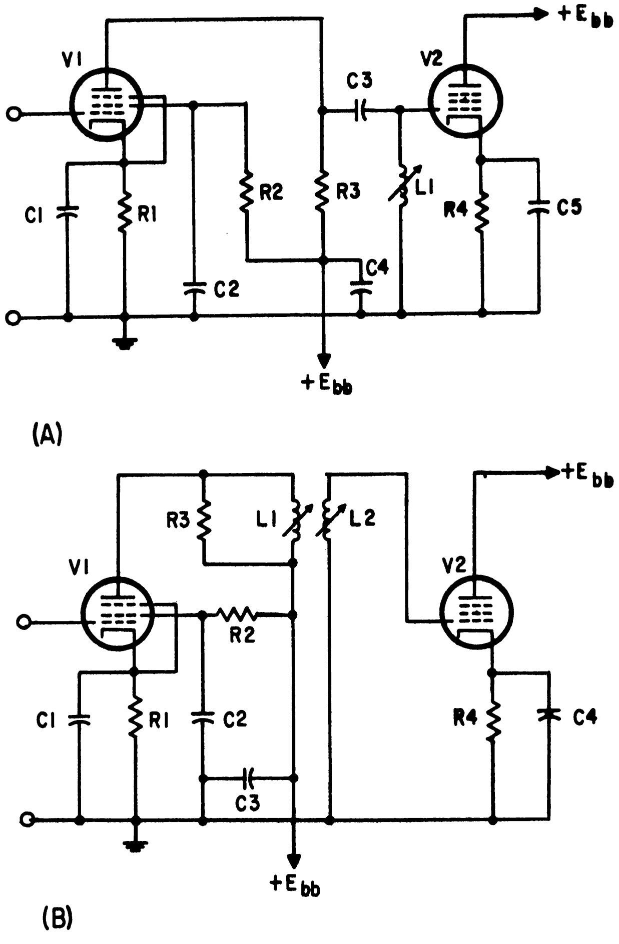


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Figure 11-17.—IF amplifier interstage coupling circuit. (A) Single-tuned; (B) double-tuned.

Although the parallel-resonant circuit in figure 11-17 (A) is not apparent, parallel resonance does occur. Inductor L1 resonates with the combination of input capacitance of tube V2, output capacitance of tube V1, and the stray wiring capacitance. Because capacitance tuning results in reduced bandwidth, it is seldom used in radar IF amplifiers. Instead, the inductance of L1 is varied by means of an adjustable tuning slug.

The overall IF gain of a multistage IF amplifier is obtained by multiplying the individual stage gains. When stage gain is specified in decibels, however, the overall gain is obtained by adding the individual stage gains. IF amplifier bandwidth is usually specified as the frequency range between points 3 db down from the center-frequency gain. Thus, a six-stage IF amplifier with a single-stage bandwidth of 10 MHz (3-db points are 5 MHz above and below the center frequency) has an overall frequency-response curve 18 db down (3 db times 6 stages) 5 MHz above and below the center frequency. As a result, the overall bandwidth is reduced considerably at the 3-db points.

Single-tuned IF amplifier stages tuned to the same frequency are called synchronously single tuned. This type of tuning is used only in relatively narrow-bandwidth IF amplifiers that require only a few stages. For radar receivers that require wide-band amplification, other arrangements of tuned circuits are used.

Double Tuning

Doubled-tuned coupling circuits are also used in IF amplifiers. Double-tuned coupling circuits result in greater IF bandwidths than do single-tuned stages. Depending on the manner of connecting load resistors, the bandwidth of a double-tuned IF amplifier is from 1.4 to 2 times that of a single-tuned IF amplifier.

When both sides of a coupling transformer are loaded equally, the increase in bandwidth is 1.4. When all of the loading is on one side of the coupling transformer, the increase in bandwidth is 2. Thus, for wide-bandwidth IF amplification, a doublt-tuned amplifier produces the same amount of gain, and uses fewer stages, than a single-tuned amplifier. Double-tuned coupling circuits, however, are more difficult to aline than single-tuned coupling circuits.

Figure 11-17 (B) is a schematic diagram of a double-tuned coupling circuit used to couple two IF amplifier stages. The double-tuned coupling circuit consists of inductors L1 and L2, the output capacitance of tube V1, the input capacitance of tube V2, and the stray wiring capacitance. Resistor R3 loads the tuned coupling circuit to obtain the required bandwidth. Replacement of this load resistor by a resistor of different value alters the receiver bandwidth.

Double-tuned coupling circuits have a flat frequency-response curve over a wide range of frequencies. However, certain combinations of single-tuned circuits in an IF amplifier also produce an overall frequency-response curve equivalent to that of a double-tuned coupling circuit.

Stagger Tuning

IF amplifiers made up of several stages tuned to different frequencies are called stagger-tuned amplifiers. A frequency-response curve similar to that of double-tuned stages can be obtained by using two IF amplifier stages tuned to different frequencies. When the Q and frequency of each stage are properly chosen, a six-stage IF amplifier consisting of three stagger-tuned pairs has an overall bandwidth twice that of six single-tuned stages tuned to the same frequency.

In alining a stagger-tuned amplifier, each stage must be tuned to the frequency for which it is designed. Improper tuning results in an irregular frequency-response curve and in distortion of the amplifier output signal. Replacement of load impedance must also be done with care, since an improper value of load impedance changes both the gain and bandwidth of the amplifier.

A useful frequency-response curve may be obtained by combining three single-tuned stages, each of which is tuned to a different frequency. The stagger-tuned triple is a combination of three single-tuned stages. One stage is tuned to the center frequency,. and the other stages are tuned above and below the center frequency. With two stagger-tuned triples (six tubes), the same gain can be obtained as with six single-tuned stages, but with an overall bandwidth 2.5 times that of the six single-tuned stages, provided that suitable circuit Q's are chosen. As in the stagger-tuned pairs, each stage of a stagger-tuned triple must be tuned to the frequency for which it is designed. If all of the stages of a stagger-tuned triple are adjusted to the same frequency, reduced bandwidth results, and all of the required radar-signal sidebands may not be amplified.

RADAR DETECTORS

After amplification to a level of a few volts, the IF signal is detected (the envelope of the RF carrier is recovered). After detection, the radar-signal envelope is applied to the video amplifiers. Thus, the detector has an IF signal input and a video signal output. The detector must have a wide video-frequency bandwidth to pass all of the required video-frequency components.

Several different tubes and circuits are used to detect the radar signal. The most frequently used radar-detector circuit employs a diode rectifier. Other radar detectors use pentodes. Pentode detectors produce greater gain, but are more complicated, than diode detectors.

Diode Detector

Figure 11-18 (A) is the schematic diagram of a diode detector. Figure 11-18 (B) shows the response of the diode detector to an applied IF pulse (input signal e_{in}). The solid line represents input signal e_{in}. The dashed line represents output voltage e_{out}.

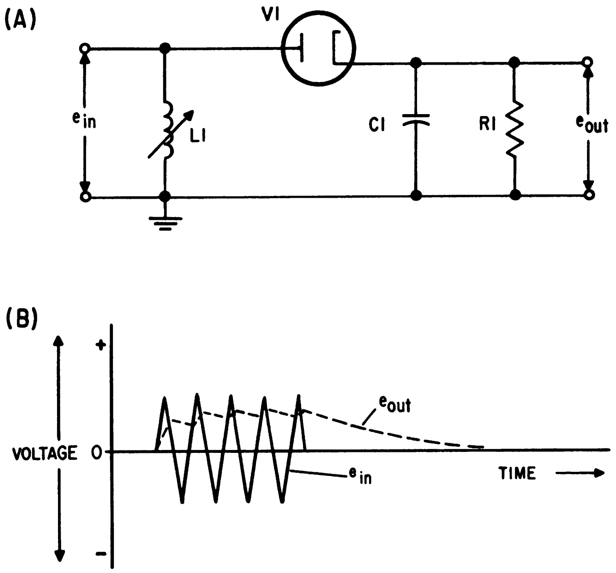

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Figure 11-18.—Radar pulse detection. (A) Diode detector schematic; (B) voltage waveforms.

Input signal e_{in} is supplied by a final IF amplifier stage to the input resonant circuit consisting of variable inductor L1, stray wiring capacitance, and the shunt capacitance across diode V1. At the start of a radar pulse, output voltage e_{out} increases rapidly, following the rise in input voltage.

The rate of rise of e_{out} depends on the values of V1 forward (conducting) resistance, V1 interelectrode capacitance, and the capacitance of C1. If the capacitance of C1 is large compared with the V1 interelectrode capacitance, most of the IF input voltage is applied across V1, and the V1 plate current is limited only by the forward resistance of V1. After several e_{in} peaks, e_{out} rises to the same value during each e_{in} peak. Between e_{in} peaks, e_{out} decreases slightly due to the discharge of capacitor C1 through resistor R1.

At the end of an IF input pulse, capacitor C1 discharges through resistor R1. The maximum rate of discharge depends on the values of resistors R1 and capacitor C1. Because R1 has a larger resistance than the forward (conducting) resistance of diode V1, the rise time of the detector output pulse is much smaller than its decay time. The decay time lengthens the output pulse. Although this effect is undesirable, it is unavoidable.

As a result of the long discharge time of capacitor C1, extreme care must be taken in replacing capacitor C1 or resistor R1. When the value of either R1 or C1 is increased, the discharge time of C1 is increased. When the value of either R1 or C1 is decreased, the C1 discharge time is also decreased.

Detector Filters

Figure 11-19 (A) is a schematic diagram of a diode detector followed by a low-pass filter. The low-pass filter consists of inductor L3 and capacitors C3 and C4. The cutoff frequency of the low-pass filter is below the intermediate frequency so as to remove IF voltage components from the detector output. If IF voltage components were allowed to reach the video-amplifier circuits, sufficient IF signal would be returned (through the power supply or stray coupling) to the input end of the IF amplifier to cause oscillation.

Video Peaking

Video peaking is a means of increasing the response of a video detector to high-frequency components of the video signal. In radio-detector circuits, high-frequency components and short decay (fall) times are not usually a problem. However, in radar detectors, the requirement of wide video bandwidth and the limitations on values of load resistance and

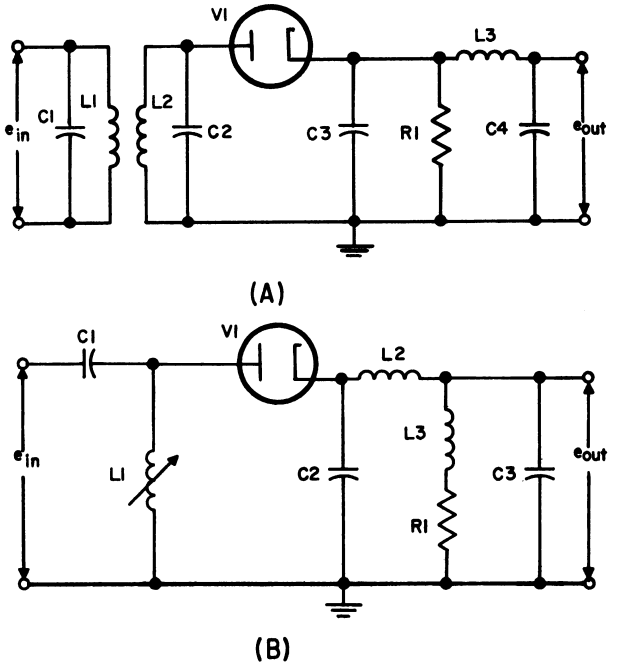

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Figure 11-19.—(A) Detector with low-pass filter circuit; (B) detector with video-peaking circuit.

capacitance make it difficult to obtain the required bandwidth. As a result, video peaking is often used.

Figure 11-19 (B) is a schematic diagram of a diode detector followed by a video-peaking circuit. Video-peaking inductors L2 and L3 have a reactance that increases with frequency. As a result, the high-frequency voltage components of a radar pulse have a high load impedance compared with the load impedance of the low-frequency voltage components.

The high-frequency voltage components develop larger voltages in the output than the lower frequency voltage components. With video peaking, video pulses are reproduced more accurately because of shorter rise times and shorter fall times.

Pentode Detectors

In the pentode detector, detection and amplification occur in one tube. Figure 11-20 (A) is a schematic diagram of a pentode plate detector. In this detector, tube V1 is biased near cutoff. The IF radar pulse (e_{in}) drives the tube above cutoff, thereby increasing the flow of V1 plate current. Because V1 is biased near cutoff, only positive peaks of the radar pulse cause plate current to flow through V1; the negative peaks are clipped. Since the V1 plate voltage is decreased during a radar pulse, a negative output pulse (e_{out}) is produced.

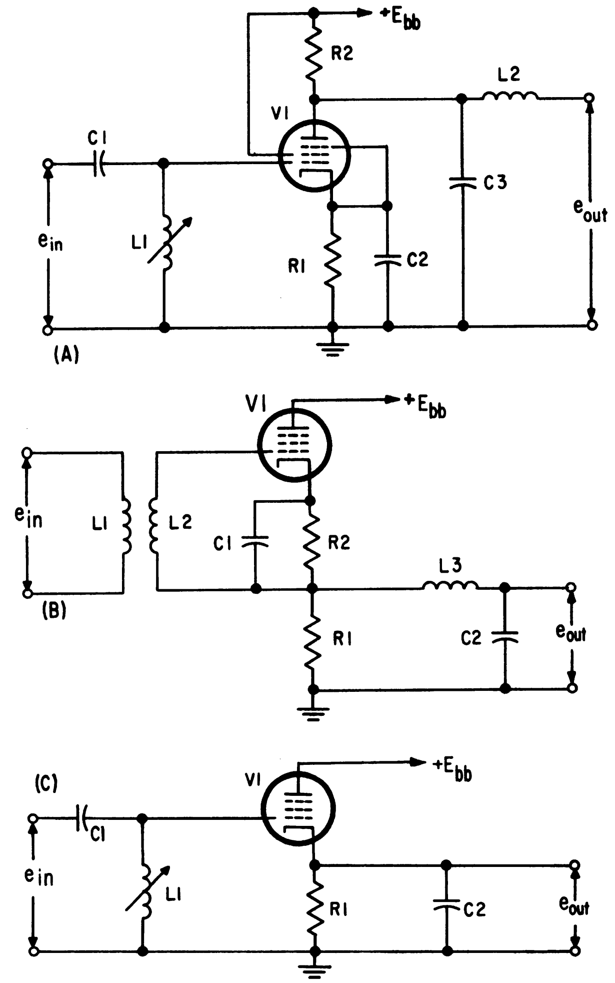

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Figure 11-20.—Pentode detectors. (A) Plate detector; (B) cathode-loaded plate detector; (C) cathode follower detector.

Figure 11-20 (B) is a schematic diagram of a cathode-loaded plate detector. Note that the load resistor (R1) is connected to the V1 cathode. Because the IF input pulse (e_{in}) is applied between the grid and cathode of V1, the load presented by R1 is the same as if R1 were connected in the V1 plate circuit (plate-loaded plate detector).

As long as the input signal is applied between V1 grid and cathode, the presence of a load resistor between V1 cathode and ground does not affect gain or signal detection. Unlike the plate-loaded plate detector (fig. 11-20 (A)), which produces a negative video output pulse, the cathode-loaded plate detector produces a positive video output pulse. In addition, the cathode-loaded detector is less sensitive to power-supply hum than the plate detector.

Figure 11-20 (C) is a schematic diagram of a cathode-follower (or infinite-impedance) detector, which consists of IF tuning inductor L1, pentode V1, cathode resistor R1, and cathode-bypass capacitor C2. This detector is called an infinite-impedance detector because (like any other cathode follower) it has a high input impedance. With tube V1 biased at cutoff, an IF input signal (e_{in}) will drive V1 above cutoff, and the V1 cathode will follow the positive peaks of the grid-signal voltage.

The advantage of the infinite-impedance detector is that it does not load the preceding IF stage. The disadvantage of the infinite-impedance detector is that its output voltage (which is always less than its input voltage) is much less than in the plate detector.

Coincidence Detection

In some circuits an output is desired only when two input signals appear at the same time (in coincidence). Several applications of this principle are found in airborne radar systems.

A basic coincidence circuit is shown in figure 11-21. Two PNP transistors are connected together at the collectors and emitters to form an emitter follower type circuit. There are two separate input terminals for the base signals. Initially, both transistors are biased to saturation conduction, and nearly all of the collector voltage is dropped across R_L. Positive signals fed to the base of each transistor will cut off the respective transistors, but both transistors must be cut off in order to produce an output. When both of the transistors are cut off simultaneously, the output terminal voltage will go in a positive direction.

This principle of detection by coincidence is used in the track gate error generator in some radars. A coincident type circuit which could be used to detect an error in time between the range gate and the selected target video is illustrated in figure 11-22.

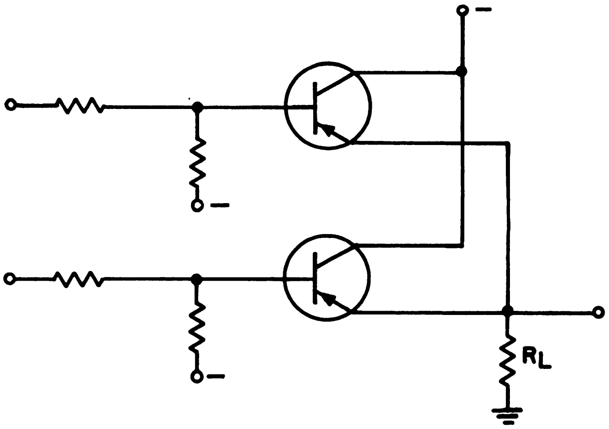

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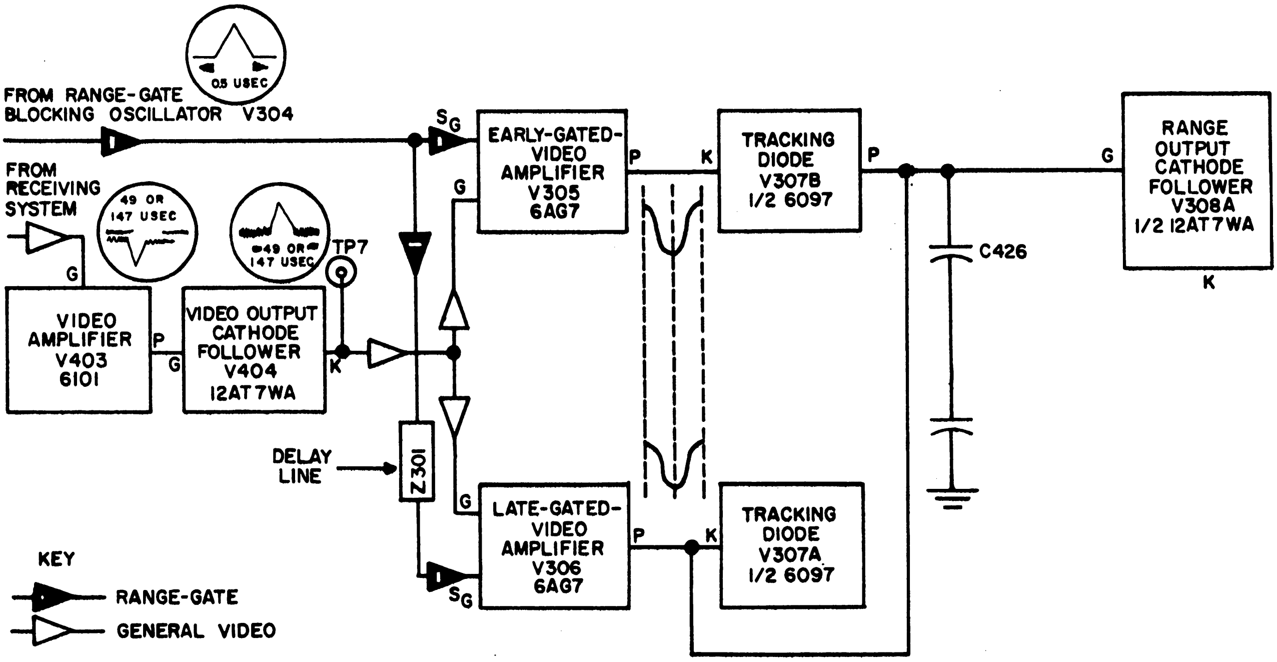
Figure 11-21.—Basic coincidence circuit.

The inputs to the circuit are the range gate from the range gate blocking oscillator and video from the receiving system. These inputs are applied in coincidence to two gated video amplifiers (pentodes) shown as V305 and V306. Normally both tubes are biased to cutoff by a positive voltage applied to the cathode through a voltage divider. Each of these tubes conducts only when sufficiently positive voltages are applied to both the control and screen grids at the same time.

All received echoes, including the selected target echo, are delivered with positive polarity from the video output cathode follower V404 to the control grids of V305 and V306. The 0.5 μsec range gate pulse from the range gate blocking oscillator is applied to their screen grids. When the target echo and range gate occur at the same range (time), V305 and V306 conduct. The output of this channel then controls the generation of the range gate so that only the selected target causes the gate video amplifiers to conduct. The duration of both the range gate and the target video signal is about 0.5 μsec. Thus, only the selected target echo may cause conduction during the gated period.

The range gate is applied directly to the screen grid of the early gated video amplifier V305 from the range gate blocking oscillator V304. The late gated video amplifier V306 receives the range gate from V304 through delay line Z301, which delays this voltage about 0.25


0.5 USEC
FROM RANGE-GATE BLOCKING OSCILLATOR V304
FROM RECEIVING SYSTEM
49 OR 147 USEC
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TP7
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VIDEO AMPLIFIER V403 6101
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VIDEO OUTPUT CATHODE FOLLOWER V404 12AT7WA
K
DELAY LINE
Z301
SG
G
EARLY-GATED-VIDEO AMPLIFIER V305 6AG7
P
K
TRACKING DIODE V307B 1/2 6097
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C426
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RANGE OUTPUT CATHODE FOLLOWER V308A 1/2 12AT7WA
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LATE-GATED-VIDEO AMPLIFIER V306 6AG7
SG
P
K
TRACKING DIODE V307A 1/2 6097
KEY
RANGE-GATE
GENERAL VIDEO

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Figure 11-22.—Track gate error detection.

microsecond. Thus, each of these gated video amplifiers can conduct for 0.5 μsec, but the periods of conduction are staggered, or overlap.

Ideally, the selected target echo arrives at the control grids so that it is centered in this staggered conduction period. The early gated stage V305 amplifies the leading half of the video each signal, and the late gated stage V306 amplifies the trailing half. As long as the video echo signal remains centered properly, the outputs of the two gated video amplifiers are equal in amplitude and duration.

If the target range decreases, the time of arrival of the video signal moves this signal further into the conduction period of the early gated stage. Consequently, the conduction time and the output of V305 increase, and the conduction time and output of V306 decrease.

When the target range increases, the video signal moves further into the conduction period of the late gated stage. How far the video signals move into the conduction period of either of the gated video amplifiers depends upon how fast the range of the target is changing.

The outputs of V305 and V306 are applied to the two halves of the tracking diode V307A and B. The output of V307A is taken from the plate and is negative; while the output of V307B is taken from the cathode and is positive.

These outputs are summed at a summing point to produce an error voltage, if any, which is used to adjust the position of the range gate. Thus, the circuit detects and continuously adjusts for any error in the tracking of the selected target.

All detectors used in radar receivers operate best on input signals of a few volts. The input signal must be large enough so that a much greater current flows during one-half of the IF voltage cycle than during the other half of the cycle. In practical detectors (diodes, crystals, and pentodes), large voltage swings are required to produce the desired current changes.

Since radar return signals (echoes) vary greatly in amplitude, special circuits are used to automatically adjust the amplification of the IF stages to produce the required output signal. These circuits, called automatic gain control circuits, are used in many radar receivers.

SPECIAL RECEIVER CIRCUITS

Gain control of radar IF amplifiers takes many different forms. The simplest type is manual gain control. More complex forms of gain control are automatic gain control (AGC), instantaneous automatic gain control (IAGC), and sensitivity time control (STC). Gain control is necessary to adjust the radar-receiver sensitivity for signals of widely varying amplitude. Some gain-control circuits are used to overcome either unintentional interference or intentional interference (jamming).

Although is is possible to control IF gain with only one IF amplifier stage, the amount of control is usually insufficient. Because a tube has capacitance between its input and output ends, a signal is coupled to the output end even when the tube is cut off. The maximum variation in gain by the control of a single stage is approximately 20 db. With two-stage gain control, approximately 40 db of gain variation can be obtained.

Automatic Gain Control

Many radar sets are provided with AGC as well as manual gain control. Provision is usually made for switching between automatic and manual gain control. In this way, manual gain control can be used, if necessary, to adjust for best reception of a particular signal.

The various types of gain control differ in the following ways:

1. Circuits used.
2. Speed of response.
3. Type of response.

The simplest type of AGC adjusts the IF amplifier bias (and gain) according to the average level of the receiver signal. AGC is not used as frequently as other types of gain control because of the widely varying amplitudes of radar return signals.

With AGC, gain is controlled by the largest received signals. When several radar signals are being received simultaneously, the weakest signal may be of greatest interest. IAGC is used more frequently because it adjusts receiver gain for each signal.

Instantaneous Automatic Gain Control

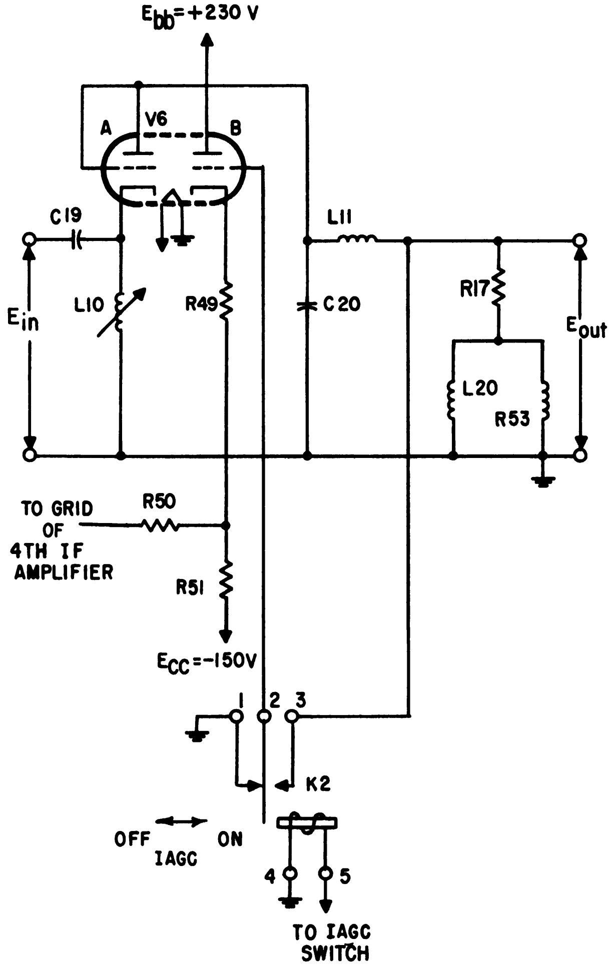

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Figure 11-23.—Second detector and IAGC circuit.

Figure 11-23 shows a schematic diagram of a typical second detector and IAGC circuit. Note that one-half of the twin triode V6 is connected as a diode, and the other half is connected as a triode amplifier. Output signal E_{out} is a negative pulse signal corresponding to the envelope of the radar return signal (echo).

When the IAGC is turned on by relay K2, the grid of V6B is connected to negative output signal E_{out}. Thus, a large output signal produces a large negative voltage on the V6B grid, thereby decreasing the V6B plate current.

Tube section V6B and resistors R49 and R51 act as a voltage divider between the negative grid-bias supply and the positive plate-voltage supply. As the V6B plate current decreases (by increasing the negative bias applied to the V6B grid) the V6B cathode becomes more negative.

Since a point between the V6B cathode and the negative grid-bias supply is connected to the grid of the fourth IF amplifier stage (not shown), the negative bias on this IF amplifier increases. Thus, the IF amplifier gain decreases as the input-signal (E_{in}) amplitude increases, and the output-signal (E_{out}) amplitude tends to remain constant. When the output-signal amplitude decreases, less negative grid bias is produced, the IF amplifier gain increases, and the output signal tends to remain constant.

The IAGC circuit is essentially a wide-band, d-c amplifier that instantaneously controls the gain of the IF amplifier as the radar return signal changes in amplitude. The range of IAGC depends on the amount of bias signal fed back to the IF amplifier. The effect of IAGC is to allow full amplification of weak signals but to decrease the amplification of strong signals. The range of IAGC is limited, however, by the number of IF stages in which gain is controlled.

In the IAGC circuit of figure 11-23, only one IF stage (the fourth IF amplifier) is controlled. Thus, the range of IAGC is limited to approximately 20 db. Although IAGC is satisfactory, sensitivity time control (STC) is more effective, because it compensates for the different amplitudes of return signals from nearby and distant targets.

Sensitivity Time Control

In radar receivers, the wide variations in return signal amplitude make adjustment of the radar-receiver gain difficult. The adjustment of receiver gain for best visibility of nearby target return signals is not the best adjustment for distant target return signals. Circuits used to adjust amplifier gain with time, during a single pulse repetition period, are called STC circuits.

Figure 11-24 shows a schematic diagram and output-voltage waveforms of an STC circuit. The input signal to the STC circuit (fig. 11-24 (A)), is a pulse obtained from the radar modulator. When the modulator pulse is applied to the grid of cathode follower V1, a large voltage appears across capacitor C1. At the same time, a negative voltage appears across capacitor C2. The amount of negative bias developed across capacitor C2 is determined by setting of potentiometer R5. A large voltage across C2 drives tube V2 beyond cutoff. Thus, E_{out} (curve D, fig. 11-24 (B)) remains constant while the voltage across C2 decays toward zero. When the voltage across C2 becomes equal to the V2 cutoff voltage, V2 begins to conduct and E_{out} rises toward zero.

Output voltage E_{out} (fig. 11-24 (A)) is applied to the grid of an IF amplifier (not shown) and thus places a constant bias on the IF amplifier grid for a short time after the modulator pulse. During this period, the IF amplifier gain is held constant. When the V2 output voltage begins to decrease, less grid bias is applied to the IF amplifier, and the receiver sensitivity increases with time. As a result, weak signals from distant targets are amplified more than signals from nearby targets.

If potentiometer R5 is set so that tube V1 is not driven beyond cutoff, the grid bias on tube V2 begins to decrease as soon as the modulator pulse ends. In this case, output voltage E_{out} rises toward zero, as shown by curve C (fig. 11-24 (B)). As a result, a large negative bias is applied to the IF amplifier at the time of the modulator pulse, thereby decreasing IF amplifier gain.

As soon as the modulator pulse ends, the grid bias applied to the IF amplifier begins to decrease, and IF amplification begins to increase. Thus the IF amplifier gain is minimum directly after a modulator pulse. Also, the gain increases at later times, when weak signals from distant targets are expected.

The combination of STC and IAGC circuits results in better overall performance than with either type of gain control alone. STC decreases the amplitude of nearby target return signals, while IAGC decreases the amplitude of larger-than-average return signals. Thus, normal changes of signal amplitudes are adequately compensated by the combination of IAGC and STC.

In some cases very large changes of signal amplitude are encountered. For example, enemy jamming may produce large amplitude interfering signals. The interfering signals may be either continuous or pulsed. The interfering-signal amplitudes may be large enough to block the receiver, and thus cover up signal return from enemy aircraft. To overcome jamming, special receiver circuits, called antijamming circuits, are used.

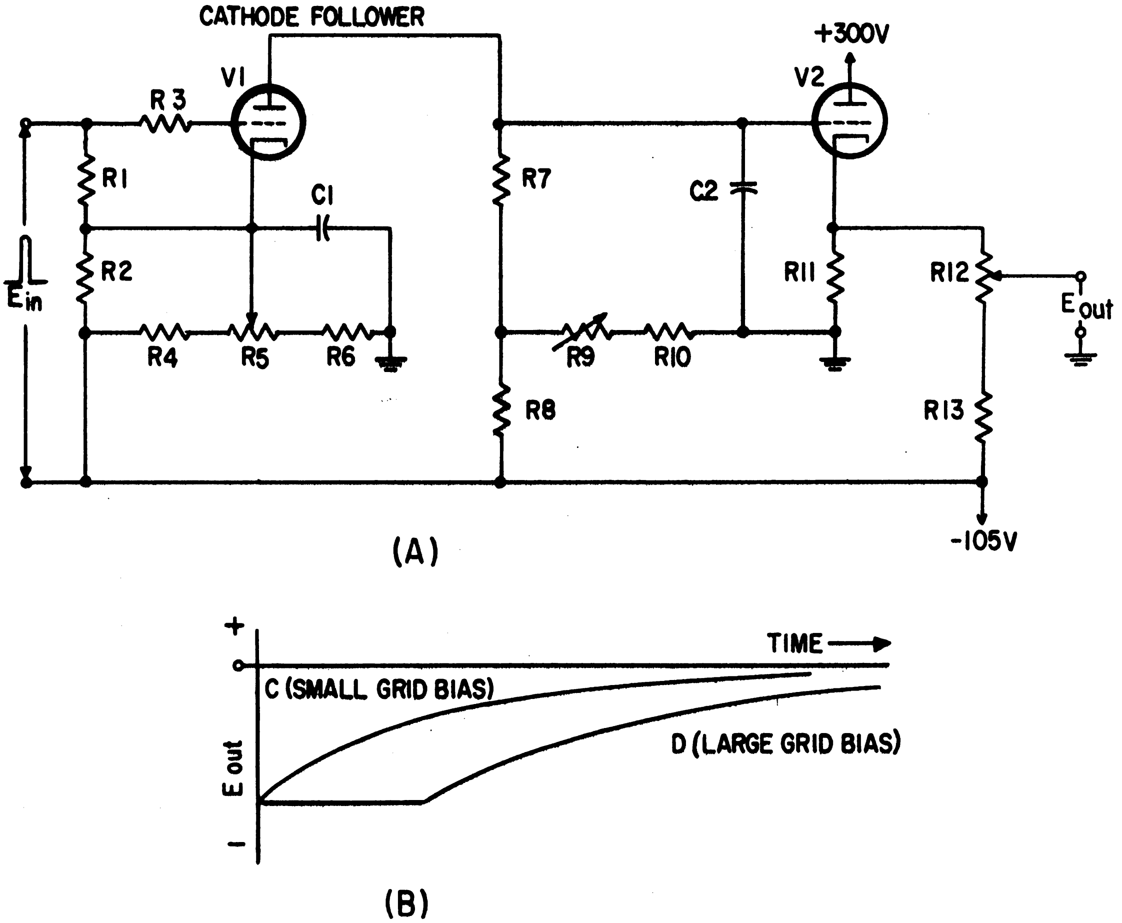

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Figure 11-24.—Sensitivity time control circuit. (A) Schematic diagram; (B) waveform of output voltage.

Antijamming Circuits

Among the many different circuits used to overcome the effects of jamming, two important ones are gated AGC circuits, and short-time-constant circuits. A gated AGC circuit permits signals that occur only in a very short time interval to develop AGC. If large amplitude pulses from a jamming transmitter arrive at the radar receiver at any time other than during the gating period, the AGC does not respond to these jamming pulses.

Without gated AGC, a large received signal from a jamming transmitter would cause the automatic gain control to follow the interfering signal and to decrease the desired signal amplitude to an unusable value. Because gated AGC produces an output signal for only short times, the AGC output voltage must be averaged over several cycles to keep the automatic gain control from becoming unstable.

Although gated AGC does not respond to signals that arrive at times other than during the desired-target return signal, AGC can do nothing with interference that occurs during the gating period. Neither can gating the AGC prevent the receiver from overloading due to jamming signal amplitudes far in excess of the desired target return signal which is being gated to set the receiver gain for a signal of that particular amplitude. As an aid in preventing radar-receiver circuits from overloading during the reception of jamming signals, short-time-constant coupling circuits are used to connect the video-detector output to the video-amplifier input circuit.

A short time constant or a fast time constant (FTC) circuit is a differentiator circuit located at the input of the first video amplifier. When a large block of video is applied to the FTC circuit, only the leading edge will pass due to the short time constant of the differentiator. A small target will produce the same length of signal on the indicator as a large target, because only the leading edge is displayed. The FTC circuit has no effect on receiver gain; and although it does not eliminate jamming signals, it greatly reduces them.

VIDEO AMPLIFIERS

Video amplifiers are used to amplify the output signal from the video detector to a level high enough to be used by the radar presentation system. Because radar receivers are frequently far removed from the presentation circuits, some video amplification is provided in the radar receivers. Video amplifiers may also be located in the radar presentation circuits (scope).

Since the radar video signal may have frequency components up to several MHz, coaxial cables are used to connect the video output circuit of the receiver to the video input circuit of the presentation system. When these coaxial cables are long, special video-amplifier circuits are generally used in the radar receiver.

Among the video-amplifier problems which must be met in radar circuits are as follows:

1. Limitation of low-frequency response. (This limitation occurs when cathode-bypass capacitors are used.)
2. Limitation of low-frequency response by screen-grid bypass capacitance (capacitance between the screen grid and ground).
3. Limitation of high-frequency response by input interelectrode capacitance, distributed wiring capacitance, and output interelectrode capacitance.

Some of the special video-amplifier circuits mentioned above, whose purpose is to compensate for these problems, are discussed in Basic Electronics.

The high frequency performance of solid-state circuits, has been improved greatly since the early devices, which were generally limited to about 500 kHz. They are now capable of operating at frequencies far above the operating range of conventional vacuum tubes. Transistors do have high frequency limitations, however; and the design of high frequency transistor circuits must take into account factors which are not significant at low frequencies.

Basically, these high frequency limitations arise because of transit time effects and the inherent junction capacitance. At high frequencies, these factors become significant and begin to affect the operation of the circuit. Stage gain is lowered, and problems involving instability appear as the impedance and gain of the transistor become complex quantities.

When transistors having an upper frequency limit only slightly higher than, or equal to, the high frequency end of the desired video band are used, the attenuation and phase shift due to the transistor must be compensated for in the amplifier. This may be accomplished by the use of compensating networks and/or the use of negative feedback.

Basically, the high frequency compensation of video amplifiers consists of attenuating the normal midrange gain of the amplifier to within a few db of the maximum gain obtainable at the highest frequency of interest, so that the bandwidth is extended to this high frequency. This is how negative feedback increases the bandwidth of an amplifier. It may be used around one or more stages, and it results in increased stability as well as bandwidth.

Two-terminal high frequency compensation circuits using two or more compensating elements are commonly used in vacuum tube circuits. These circuits can also be used for the high frequency compensation of transistor amplifiers, although the design relationships are not quite as straightforward. This method of high frequency compensation consists essentially of using RLC peaking circuits to maintain a nearly constant current amplification factor over the required band.

The three-stage 50-MHz wide-band amplifier shown in figure 11-25 (A) uses negative feedback frequency compensation in conjunction with an RLC compensating network placed directly in the feedback path. This arrangement provides 34 db of negative feedback from 50 kHz to 5 MHz.

The current amplification factor is virtually flat at 34 db from d.c. to 10 MHz, and within 3 db to 50 MHz. The feedback RLC network maintains the feedback loss flat to 10 MHz.

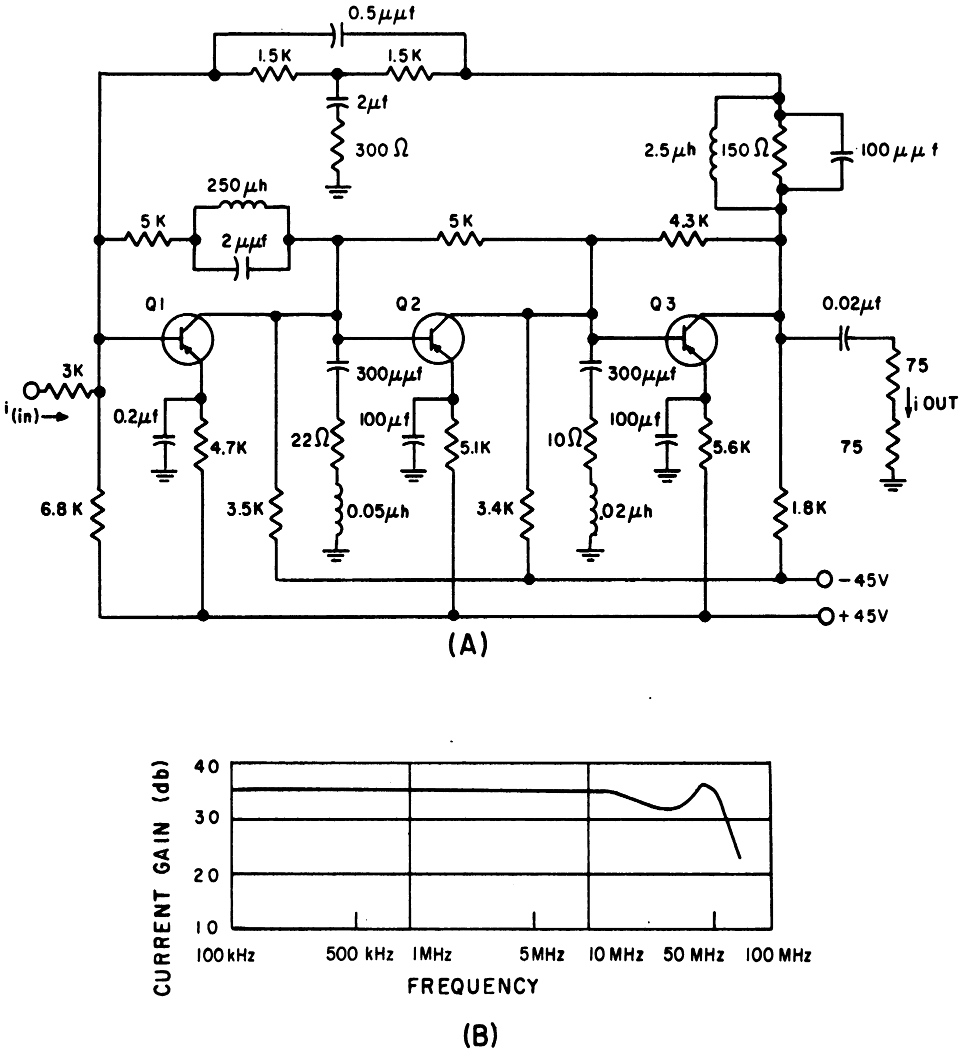

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Figure 11-25.—Three-stage 50-MHz video amplifier. (A) Circuit; (B) frequency characteristic.

The interstage RLC networks compensate the gain characteristic between 5 and 100 MHz, and the feedback around the first stage provides compensation in the vicinity of 7 MHz. The emitter bypass capacitors control the frequency response from d.c. up to approximately 50 kHz. The frequency characteristic of the amplifier is shown in figure 11-25 (B).

Video signals are usually coupled to the presentation circuits through relatively long lengths of low-impedance, large-capacitance coaxial cables. Thus, video output stages generally have a low output impedance.

These coaxial cables may have a capacitance of 20 μμf per foot. Thus, a 5-foot cable would have a capacitance of 100 μμf. To prevent attenuation of high-frequency signals by the shunt capacitance, coaxial cables must be terminated in their characteristic impedance (usually 100 ohms or less).

For coaxial cables that are very short (less than a quarter-wavelength long), the termination resistance may be higher than the characteristic impedance without affecting high-frequency response. Higher values of terminating resistance result in higher output voltages.

AUTOMATIC FREQUENCY CONTROL

Automatic frequency control (AFC) is used to automatically adjust the local-oscillator frequency so that the radar receiver is always tuned to the radar-transmitter frequency.

AFC systems are classified in accordance with their method of operation. The method of operation may be divided into two major classifications, the absolute and the difference frequency systems.

In the absolute frequency system the frequency of oscillation is determined by a precision frequency standard such as a high-Q cavity. This system is generally used to keep the receiver tuned to the beacon frequency. In the difference frequency system the local oscillator is maintained on a frequency which is greater or less than the magnetron frequency by an amount equal to the intermediate frequency. This keeps the receiver tuned to the magnetron during search operation.

Either of these systems may be a nonhunting or hunting type construction. The hunting system is constructed to cause the oscillator to sweep a wide frequency range. This enables the oscillator to find the correct operating frequency and automatically remain on this frequency. This system has the advantage that in the event of a sudden shift in magnetron or local-oscillator frequency the correct operating frequency is found automatically. In the nonhunting system the oscillator is manually tuned to the correct frequency and maintained electronically to this frequency.

The frequency of UHF and microwave oscillators is very sensitive to changes in load impedance. Thus, as the transmitting antenna of a UHF or microwave radar is rotated, the transmitter frequency may change. These frequency changes may be so great that the received signal is outside the receiver pass band. Transmitter frequency changes may also be caused by variations in cavity, waveguide, and antenna components due to heating or by changes in supply voltage as well as other reasons. In addition to transmitter frequency changes, the local oscillator is also subject to frequency changes. In all these cases, AFC is used to automatically tune the radar receiver to the transmitter frequency.

Although many different types of AFC circuits are used in UHF and microwave radars, all AFC systems are basically similar in operation. Practically every AFC system has circuits that produce an output voltage proportional to the change in transmitter frequency (or to be more precise, the change in IF frequency). This output voltage changes the local-oscillator output frequency in such a way that the resultant IF signal frequency remains essentially constant.

Figure 11-26 shows a block diagram of an AFC circuit used with radar. The IF input signal to the AFC circuit's IF amplifier is supplied from the receiver mixer. The IF amplifier is turned off and on by a gating pulse from the receiver range unit. Thus, the AFC circuit's IF amplifier is sensitive only during a transmitter pulse. The output of the IF amplifier is applied to the discriminator, which produces an output pulse whose amplitude and polarity are proportional to the change in IF signal frequency.

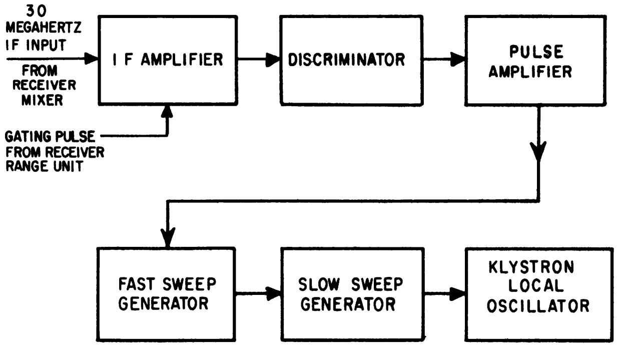

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Figure 11-26.—AFC circuit, block diagram.

If the IF signal is at the discriminator center frequency, no discriminator output pulse results. If the IF signal is either above or below the center frequency, a positive or negative discriminator output pulse results. The discriminator output pulse is amplified by the pulse amplifier, and applied to the fast sweep generator.

When no pulse reaches the fast-sweep generator, the slow-sweep generator (fig. 11-26) produces a sawtooth sweep voltage that is applied to the repeller electrode of the klystron local oscillator. Since klystron frequency is varied by changes in repeller voltage, the sawtooth voltage causes the klystron local oscillator to sweep through a wide range of frequencies. As the local-oscillator frequency changes, the frequency of the mixer output signal also changes.

When the frequency of the mixer output signal is approximately 30 MHz, the AFC discriminator applies a pulse to the fast sweep generator. When a positive pulse is applied to the fast sweep generator, it assumes control of the sweep voltage. The fast sweep generator produces a low-amplitude, high-frequency, sawtooth voltage that keeps the radar receiver closely tuned to the radar transmitter frequency.

RADAR INDICATORS

The various types of radar indicators (A-scope, B-scope, PPI-scope, etc.) and some of the fundamental principles of their operation are discussed in Basic Electronics. Review of the basic principles before continuing with the present discussion is recommended. In the following paragraphs, details of radar indicator operation which go beyond the basic level are presented.

A-SCOPE

Figure 11-27 is the simplified block diagram and scan presentation of a typical A-scope. Although the A-scope is not used in modern weapons systems radar, it is presented to establish a basic understanding of scopes before discussing the more advanced type. In the operation of the A-scope an initial trigger pulse from the timer is applied to both the radar transmitter and the one-shot (monostable) multivibrator in the A-scope. The one-shot multivibrator generates the following:

1. A negative gate pulse that is fed to the range marker generator.
2. A negative gate pulse that is fed to the range sweep generator.
3. A positive gate pulse that is fed to the control grid of the cathode-ray tube.

The gate pulse to the range marker generator causes a series of equally spaced range marks to be generated. These range marks are added to the receiver output signal in the video mixer. The output of the video mixer is applied between ground and one vertical-deflection plate of the cathode-ray tube. The other vertical-deflection plate is connected to the vertical-centering control. (In some cases, the receiver output signal is applied to one vertical-deflection plate, and the range marks are applied to the other vertical-deflection plate.)

The negative gate pulse, fed to the range sweep generator, causes a nearly linear sawtooth sweep voltage to be generated. In general the different timing capacitors in the one-shot multivibrator and in the range sweep generator are connected to a common range switch. In this way, the RC time constants of both circuits are changed simultaneously when the operating range is changed.

When the duration of the negative gate pulse is changed, the duration of the sawtooth sweep voltage is changed, but the amplitude of the sweep voltage is unchanged. Hence, for different operating ranges, the scanning spot travels approximately the same distance across the A-scope screen. However, the speed of the scanning spot increases as the range setting is decreased.

The sawtooth output of the range sweep generator is amplified by the range sweep amplifier, and then applied to the paraphase amplifier (phase splitter). The paraphase amplifier permits the sawtooth sweep voltage to be applied in push-pull to the horizontal-deflection plates of the cathode-ray tube. This reduces defocusing of the electron beam, which usually results when the sweep voltage is applied to only one horizontal-deflection plate.

The positive gate pulse applied to the control grid of the cathode-ray tube intensifies the electron beam during the sweep time. This enables the output of the video mixer to be displayed on the A-scope screen. When the positive gate pulse is removed, blanking results (the electron beam is cut off).

Clamping circuits are frequently used with A-scopes to keep the display properly positioned despite changes in the average (d-c) value of the sweep or signal voltages. (Remember, clampers hold one part of the signal waveform at a constant voltage level.) In some A-scopes, expanded sweep circuits are used. These circuits enable a small section of the sweep to be expanded to cover the A-scope screen. Thus, more accurate range measurements can be made.

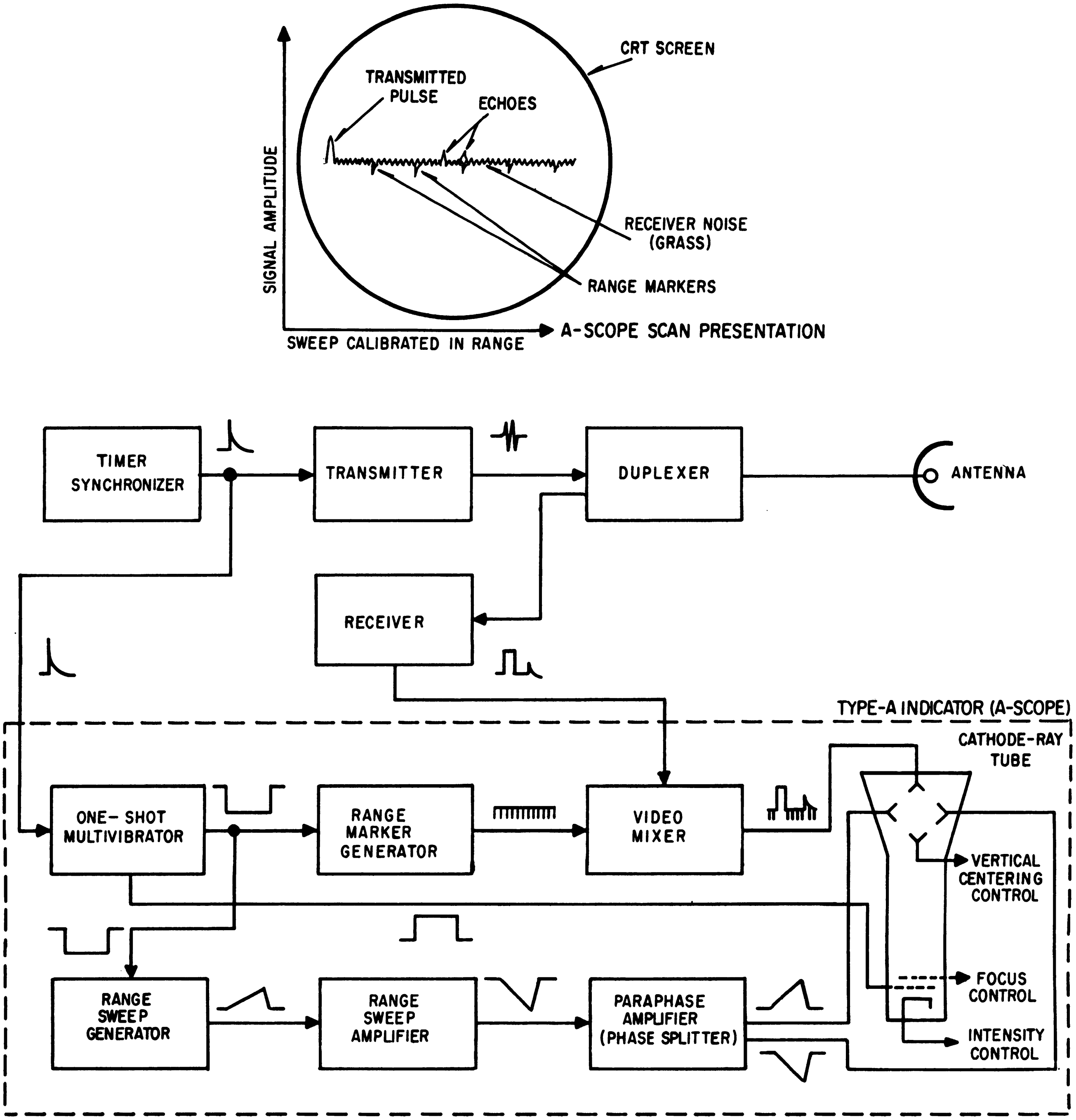

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Figure 11-27.—Typical A-scope block diagram and scan presentation.

B-SCAN

Often the situation in which a radar is used calls for simplicity of circuitry and construction; therefore, B-scan is often used.

In B-scan, three variables are possible. These are range, a function of time; azimuth, a function of antenna rotation; and the intelligence received by the radar or associated equipment.

From the operator's standpoint, the ideal situation would be the presentation of an exact replica of the area scanned. This would involve complicated construction and circuitry. The B-scan represents a compromise between the extremes of simple and complex circuitry.

B-scan involves the simplest circuitry and construction of any two-dimensional presentation and yet presents information in a reasonably faithful replica of the area scanned by the antenna (figure 11-28). It works best under conditions where the antenna scans a sector of less than 180°, but it can be employed in a situation where a 360° area is scanned.

Azimuth is presented horizontally by the use of a potentiometer that is mechanically connected to the antenna. The output of the potentiometer controls the horizontal push-pull amplifiers which in turn controls the horizontal deflection.

The intelligence is presented on the indicator by intensity-modulating the sweep. The antenna scanning speed is approximately one scan per second, whereas the sweep speed is at the PRF rate; therefore, the intelligence will also have range and bearing.

C-SCOPE

Type-C indicators, or C-scopes (fig. 11-30) are used primarily to present data on the bearing and elevation of targets. Type-C indicators may sometimes be used in aircraft interception. Like B-scopes, C-scopes provide a rectangular display on their screens. However, in C-scopes the vertical axis represents elevation, and the horizontal axis represents bearing.

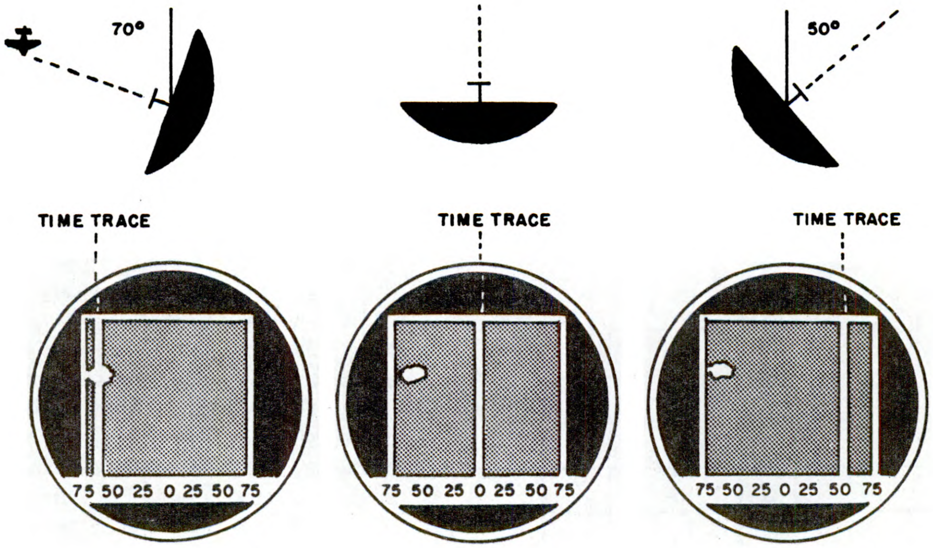

Figure 11-28.—B-scan presentation.

Range is usually presented vertically by the use of a conventional sweep circuit. (Refer to the B-scope block diagram in figure 11-29.) The scope presentation may be created by either magnetic or electrostatic deflection. Since electrostatic deflection is usually employed, the final amplifiers are operated push-pull to gain the advantage of good sweep linearity.

Thus, in aviation fire control radar, targets may appear on either side of both the horizontal and vertical axes.

To obtain a rectangular display on the screen of a C-scope, both horizontal- and vertical-sweep generators are used. Since the sweep frequencies are relatively low, potentiometers (like the azimuth sweep potentiometer of the

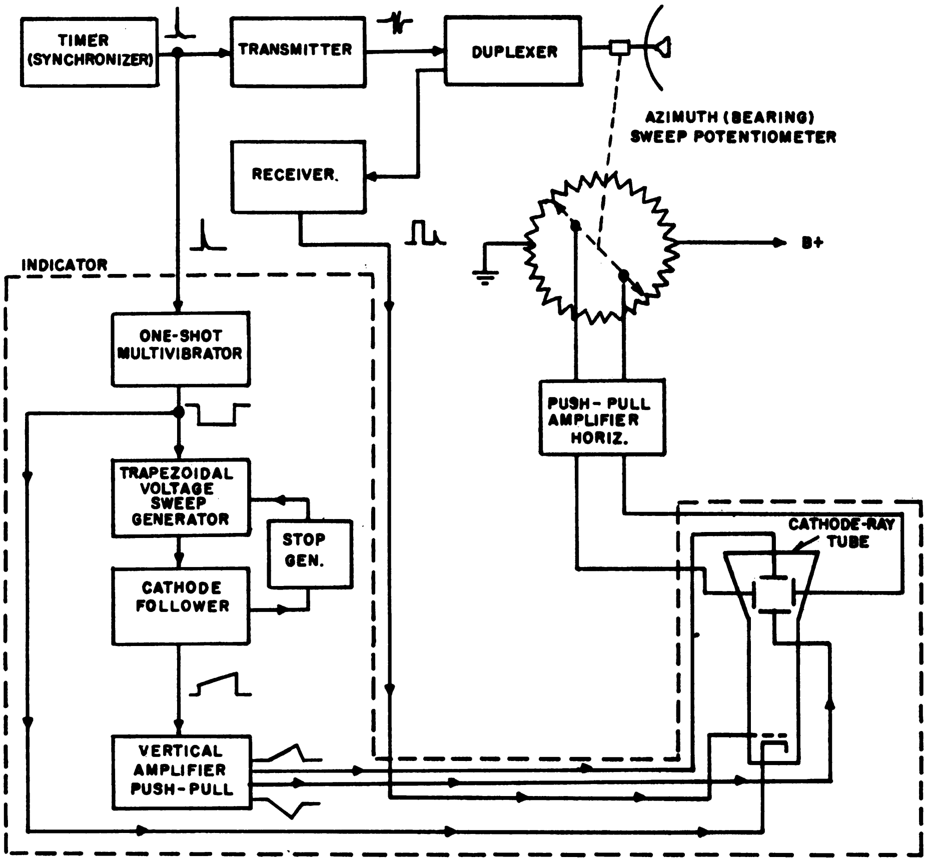
TIMER (SYNCHRONIZER)
TRANSMITTER
DUPLEXER
AZIMUTH (BEARING) SWEEP POTENTIOMETER
RECEIVER.
B+
INDICATOR
ONE-SHOT MULTIVIBRATOR
TRAPEZOIDAL VOLTAGE SWEEP GENERATOR
STOP GEN.
CATHODE FOLLOWER
PUSH-PULL AMPLIFIER HORIZ.
CATHODE-RAY TUBE
VERTICAL AMPLIFIER PUSH-PULL

Figure 11-29.—Block diagram of a B-scope system. AQ.463

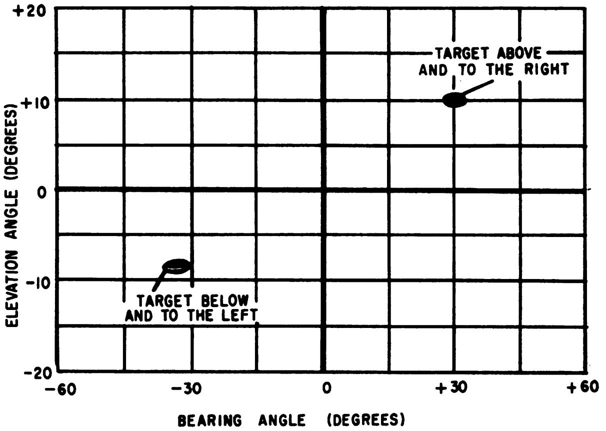

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Figure 11-30.—C-scope presentation.

B-scope) are generally used. These potentiometers are connected to the radar antenna.

When the antenna turns sideways, the scanning spot on the C-scope screen is deflected horizontally. When the antenna is tilted up or down, the scanning spot is deflected vertically. Echo signals applied to the control grid (or cathode) of the cathode-ray tube during the sweep period cause the brightness of portions of the horizontal trace to be increased. The position of a bright spot indicates the elevation and bearing of a target.

Targets at different ranges, but with the same bearing and elevation, appear as a single spot on a C-scope. Targets of this kind cannot be distinguished individually on the C-scope. For this reason, an indicator that presents range data is generally used in conjunction with a C-scope. Once the range of a particular target has been determined, a range gate pulse (rectangular pulse) is applied to the C-scope. This intensifies the electron beam only for the duration of the range gate pulse. Thus, only the desired target echo appears on the C-scope; all other signals are blanked out. In this way, the bearing and elevation of a particular target at a specific range can be determined.

When used in conjunction with modern aviation weapons systems radars, C-scopes will generally be used to display information obtained from an infrared (IR) detector.

PPI-SCOPE

Type-P indicators, also called plan-position indicators (PPI), or PPI-scopes, are used primarily to present data on the range and bearing of targets. Like B- and C-scopes, PPI-scopes generally use cathode-ray tubes with long-persistence screens.

The PPI presentation is practically an exact replica of the region scanned by the radar antenna.

Distance along the radial sweep line represents target range. Rotation of the radial sweep line, in synchronism with the antenna's rotation, produces a circular display.

When echo signals are applied to the control grid (or cathode) of the PPI cathode-ray tube during the sweep period, the brightness of portions of the radial sweep line is increased. As in B-scopes, increasing the brightness of some portions of the PPI radial sweep line results in a maplike picture. Figure 11-31 shows a typical PPI presentation.

Normally, the center of the PPI screen represents the location of the radar. The range and bearing of the target can be determined by means of either an engraved transparent overlay, or electronic range circles and an engraved azimuth (bearing) scale. Range circles are usually obtained by adding uniformly spaced pulses to the receiver output signal during the sweep period.

The pulses cause bright spots to appear at equal intervals along the radial sweep line. When the radial sweep line rotates, the spots produce concentric circles. The distance between the center of the PPI screen and a range circle indicates a specific distance.

A movable azimuth index is frequently used to facilitate azimuth (bearing) measurements. The movable azimuth index is scribed on a glass window. The window is rotated by turning a special knob, usually mounted on the PPI chassis. When the window is rotated so that the movable azimuth index coincides with a target echo, the bearing of the target can be determined by noting the position of the index on the azimuth scale.

Figure 11-32 shows a simplified block diagram of a typical PPI-scope. In the case illustrated, the cathode-ray tube has a fixed deflection yoke. The sawtooth sweep currents required to produce the rotating radial sweep line are obtained from the trapezoidal-voltage sweep generator, a rotary transformer (synchro resolver), and two push-pull amplifiers. (See chapter 13 of this course for a discussion on resolvers.)

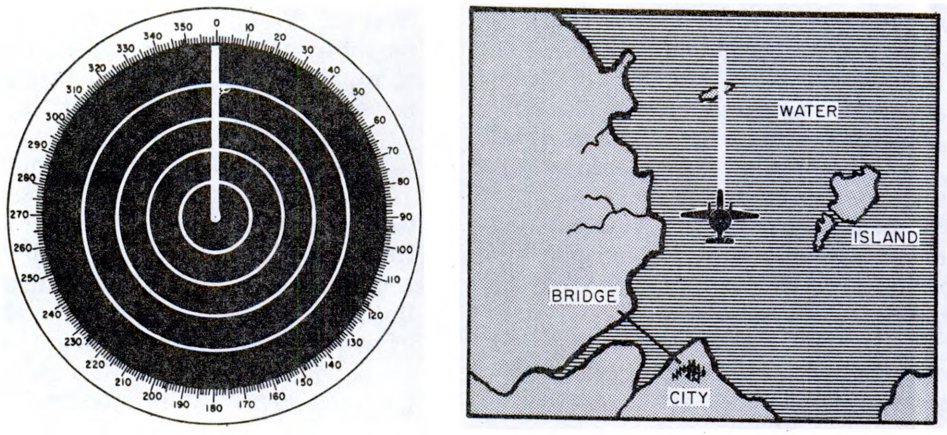
The rotary transformer is a variable-ratio transformer with one primary winding (the rotor) and two secondary windings (the stator). The voltage ratio between the primary winding and each secondary winding changes when the rotor is turned.

The rotor is connected mechanically to the radar antenna. Thus, when the antenna turns, the rotor turns, and the voltage ratio changes. One secondary voltage varies as the sine of the angle of antenna rotation; the other secondary voltage varies at the cosine of the angle of antenna rotation.

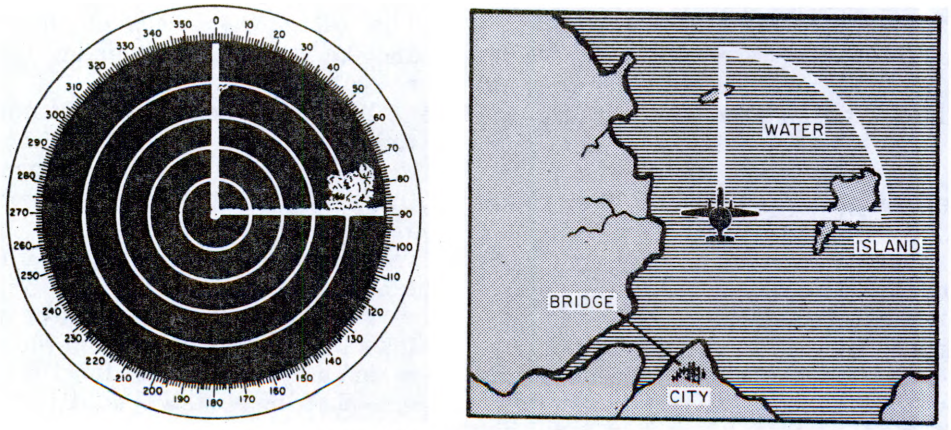
The plan-position indicator operates as follows: Trigger pulses from the timer (synchronizer) are fed to both the transmitter and the one-shot monostable multivibrator. The one-shot multivibrator generates negative gate pulses that are applied to the trapezoidal-voltage sweep generator and the cathode of the cathode-ray tube.

The output of the trapezoidal-voltage sweep generator is fed to a power amplifier. The output of the power amplifier is applied to the primary of the rotary transformer. The secondary voltages of the rotary transformer are trapezoidal and have amplitudes that depend on the antenna position.

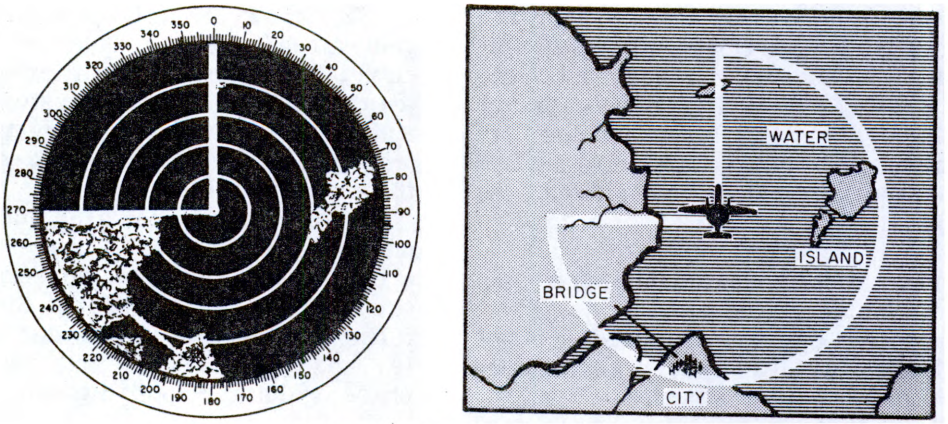
To apply trapezoidal voltages to the two push-pull amplifiers, a center-tapped resistance network is connected across each of the two secondary windings of the rotary transformer. Network R1 produces two voltages (e_1 and e_2) of equal amplitude and opposite phase, which are applied to one push-pull amplifier. Likewise, network R2 produces two voltages (e_3 and e_4) of equal amplitude and opposite phase, which are applied to the other push-pull amplifier. For simplicity, only the waveforms of e_1 and e_3 are shown in figure 11-32.



ANTENNA POINTING DIRECTLY AHEAD (0°)



ANTENNA POINTING TO 90°



ANTENNA POINTING TO 270°

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Figure 11-31.—PPI presentation.

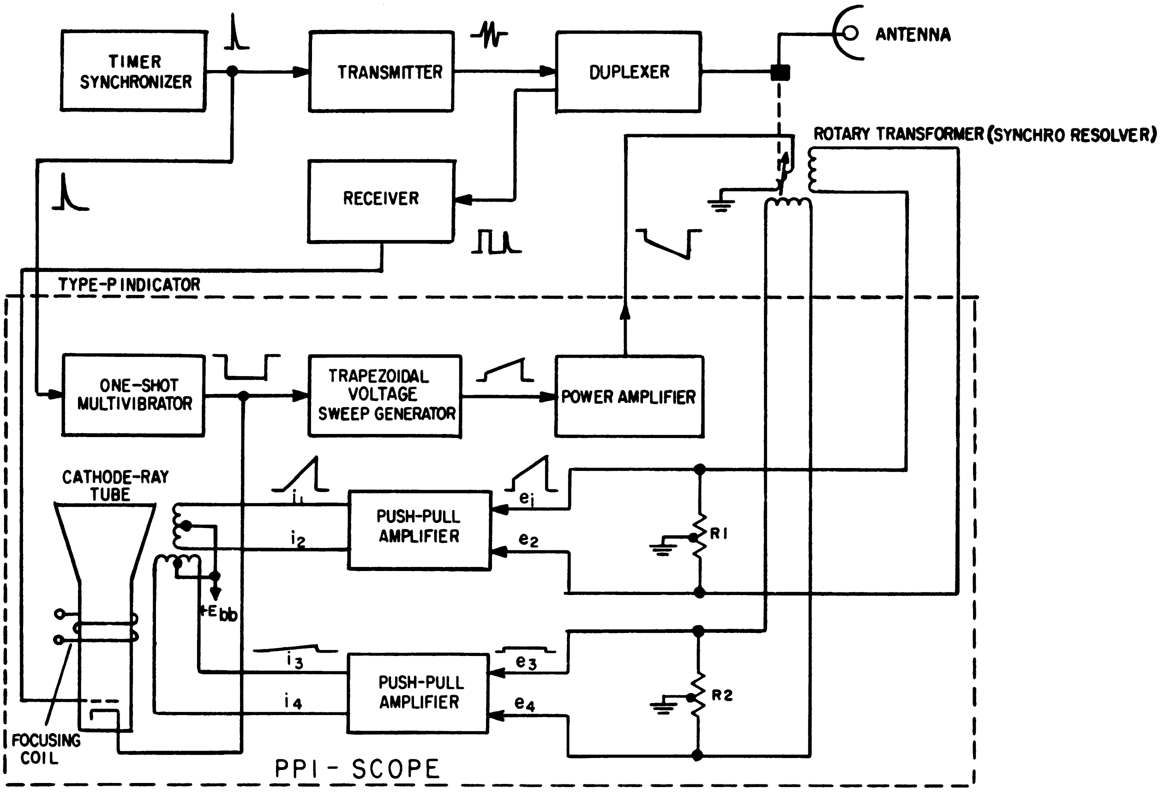

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Figure 11-32.—Typical PPI-scope, block diagram.

Trapezoidal voltages e_1 and e_2 produce sawtooth sweep currents i_1 and i_2, respectively. Trapezoidal voltages e_3 and e_4 produce sawtooth sweep currents i_3 and i_4, respectively. The angular position of the radial sweep line at any instant depends on the relative amplitudes and the phase relationship of the sawtooth sweep currents at that instant.

Sawtooth sweep currents i_1 and i_2 are equal in amplitude, but opposite in phase. Likewise, i_3 and i_4 are equal in amplitude, but opposite in phase. For simplicity, only the waveforms of i_1 and i_3 are shown in figure 11-32. The relative amplitudes and polarities of i_1 and i_3 (also of i_2 and i_4) vary as the rotary transformer is rotated. This causes the radial sweep line to rotate in synchronism with the radar antenna (which is geared to the rotary transformer).

In general, plan-position indicators used in conjunction with rotary transformers also use clamping circuits (clampers). The clamping circuits insure that the scanning spot always starts from the same point on the PPI screen. The fundamentals of clamping circuits are discussed in Basic Electronics.

Negative gate pulses are applied to the cathode of the PPI cathode-ray tube to intensify the electron beam during each sweep period. The electron beam is intensified to the point where the radial sweep line is barely visible. When echo signals are applied to the control grid of the cathode-ray tube during each sweep period the brightness of portions of the radial sweep line is increased.

DEFLECTIONS AND SWEEPS

The various types of deflection and sweep circuitry required for a typical radar indicator system are shown in figure 11-33 (A). These circuits, together with the receiver circuits, are contained in a unit called the receiver-indicator. Figure 11-33 (B) shows

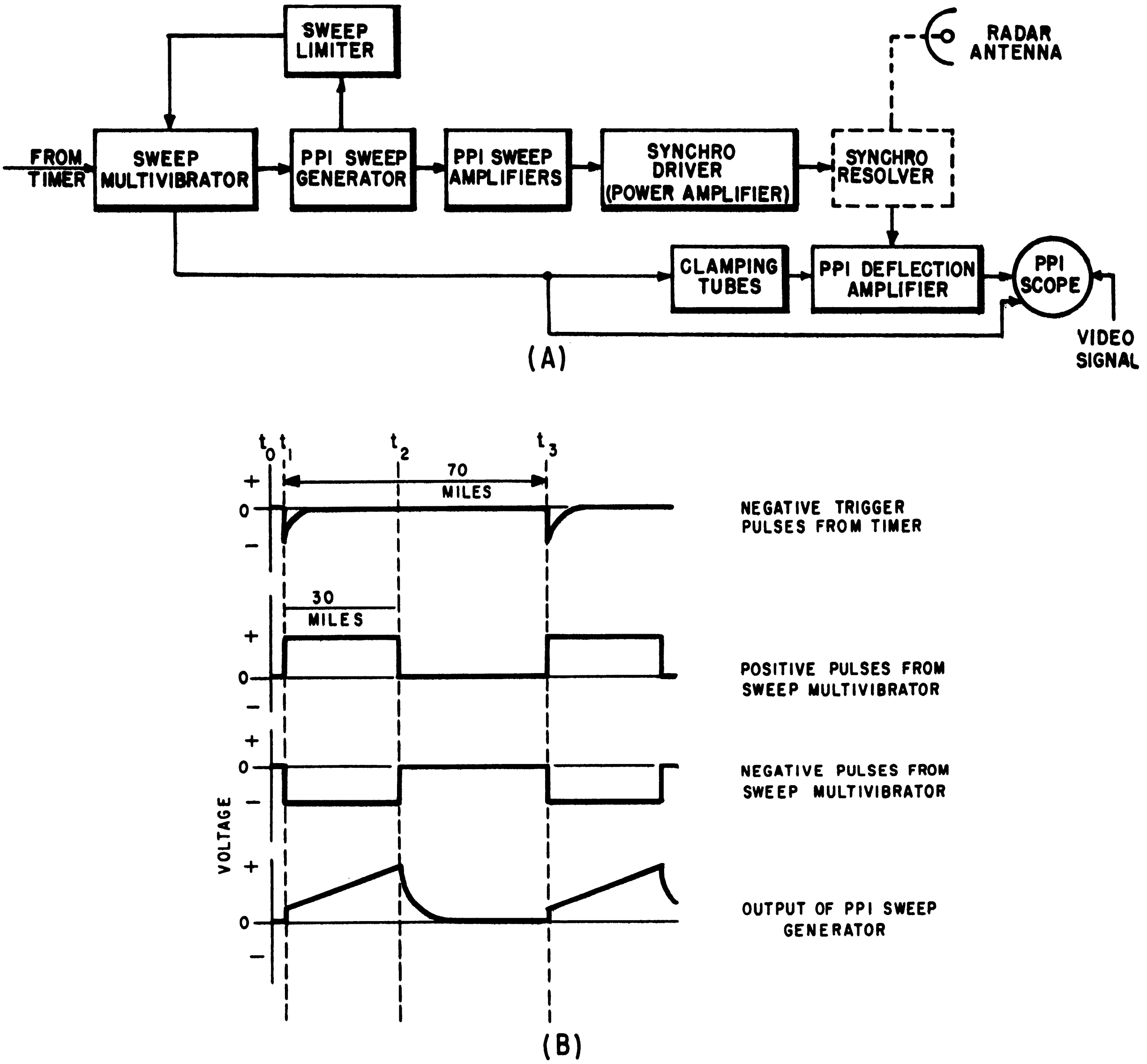

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Figure 11-33.—(A) Typical indicator, block diagram; (B) waveforms for 30-mile sweep.

the waveforms for this indicator system when set for a 30-mile range sweep.

Negative trigger pulses from the timer are applied to the sweep multivibrator. When a negative trigger pulse is applied to it, the sweep multivibrator causes a switching action which initiates the sweep voltage in the PPI sweep generator.

When the sweep voltage reaches a predetermined level, the sweep-limiter tube conducts, and causes a second switching action. As a result, the sweep multivibrator produces positive and negative rectangular pulses, as shown in figure 11-33 (B). The positive rectangular pulses are applied to the PPI sweep generator which produces a trapezoidal voltage.

The trapezoidal voltage is amplified by the PPI sweep amplifiers, and then applied to the synchro driver (power amplifier). The output of the synchro driver is applied to the rotor of a synchro resolver.

The synchro resolver has two stator windings and one rotor winding. The rotor shaft is mechanically coupled to the radar antenna. When the antenna rotates, the synchro-resolver rotor turns, and trapezoidal-sweep voltages of varying amplitude are induced in the synchro-resolver stator windings. The amplitude of the induced sweep voltages, at any instant, depends on the angular position of the rotor winding with respect to the stator windings of the synchro resolver.

The induced sweep voltages are amplified by the PPI deflection amplifiers, and then applied to the deflection coils of the PPI-scope. As a result, a radial sweep line is produced on the PPI screen. Because of the mechanical coupling between the radar antenna and the synchro-resolver shaft, the radial sweep rotates in synchronism with the antenna.

The negative rectangular pulses from the sweep multivibrator are applied to the clamping tubes and the cathode-ray tube of the PPI-scope. The clamping tubes insure that the PPI electron beam always starts its sweep trace from the same point on the PPI screen.

The negative rectangular pulses applied to the cathode-ray tube intensify the scope electron beams during the sweep time. This produces a faintly visible trace on the scope.

Radial Sweep Line

The radial sweep line on the screen of a plan-position indicator is obtained by sweeping the electron beam from the center to the edge of the PPI screen. To obtain azimuth (bearing) indication, the radial sweep line is rotated about the center of the screen, like a spoke of a wheel. Two different methods that are used to produce a rotating radial sweep line are mechanical azimuth sweep and electrical azimuth sweep.

In mechanical azimuth sweep (fig. 11-34), a rotating deflection yoke is used. The yoke is mounted in bearings, and is rotated mechanically around the neck of the cathode-ray tube, in synchronism with the radar antenna.

When a sawtooth sweep current is applied to the deflection coil through the sliprings, as shown in figure 11-34 (B), a sawtooth magnetic field is produced. The magnetic field causes the electron beam to be deflected, thereby producing a radial sweep line. The amount of beam deflection, and consequently, the length of the radial sweep line, depend on the amplitude of the sawtooth sweep current.

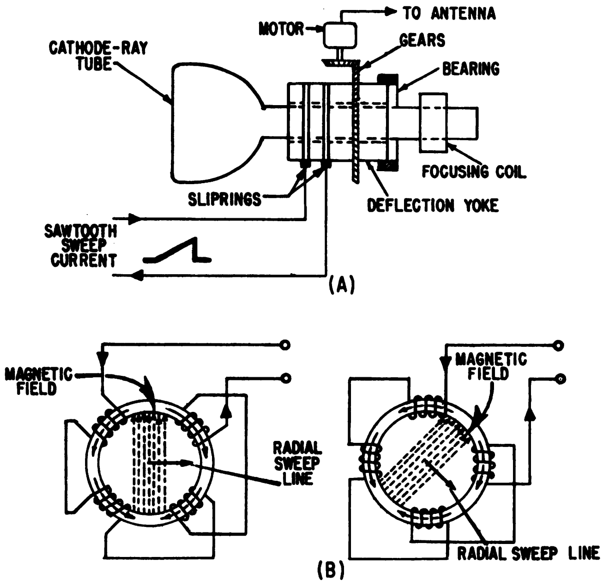

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Figure 11-34.—Mechanical azimuth sweep. (A) Rotating deflection yoke; (B) relationship between sweep direction and yoke position.

The direction of beam deflection, and consequently, the position of the radial sweep line, are always perpendicular to the magnetic field. Thus, when the deflection yoke rotates, the deflection coil rotates, and the magnetic field also rotates.

Since the electron beam is always deflected in a direction perpendicular to the magnetic field, the radial sweep line also rotates. A radial sweep line is produced each time a sawtooth sweep current is applied to the deflection coil. The radar antenna and the rotating yoke are always rotated in synchronism.

The second method of producing a rotating radial sweep line is called electrical azimuth sweep. This system uses a fixed deflection yoke with horizontal- and vertical-deflection coils. Sawtooth sweep currents are applied simultaneously to the two deflection coils. The direction of the radial sweep line obtained depends on the relative amplitudes of the two sweep currents. Unlike mechanical azimuth sweep, electrical azimuth sweep has practically no mechanical difficulties.

In the foregoing paragraphs, frequent mention has been made of the PPI sweep generator circuits. Some of the fundamentals of sweep generators are covered in Basic Electronics in connection with special circuits and cathode-ray tube fundamentals. Further details of PPI sweep generator circuitry are beyond the scope of this manual.

MISCELLANEOUS PRESENTATIONS

Many other types of radar indicators are used in addition to A-scopes, B-scopes, C-scopes, and PPI-scopes. It is not unusual to find more than one type of presentation incorporated into one indicator.

Most indicators used in aviation fire control radar use two or more electron guns. One gun is used to develop a B-type presentation while the other gun or guns develop the various elements of a so-called attack presentation. These elements may consist of an elevation strobe, artificial horizon, steering information, acquisition circle, and range circle. Coverage of all these elements with the time sharing necessary for proper display is discussed in chapter 12 of this manual. However, the range circle element is discussed in succeeding pages of this chapter.

RANGE CIRCLE GENERATOR

The indicator of a typical aircraft weapons systems radar uses a circle for range presentation. The size of this circle will be directly proportional to the target range. Figure 11-35 is a simplified schematic diagram of a range circle generator.

The AQ should already be familiar with the method of producing a circle on a CRT by applying two sine waves, 90° out of phase, to the deflection plates of the CRT. The size of the circle is controlled by the amplitude of the sine wave inputs.

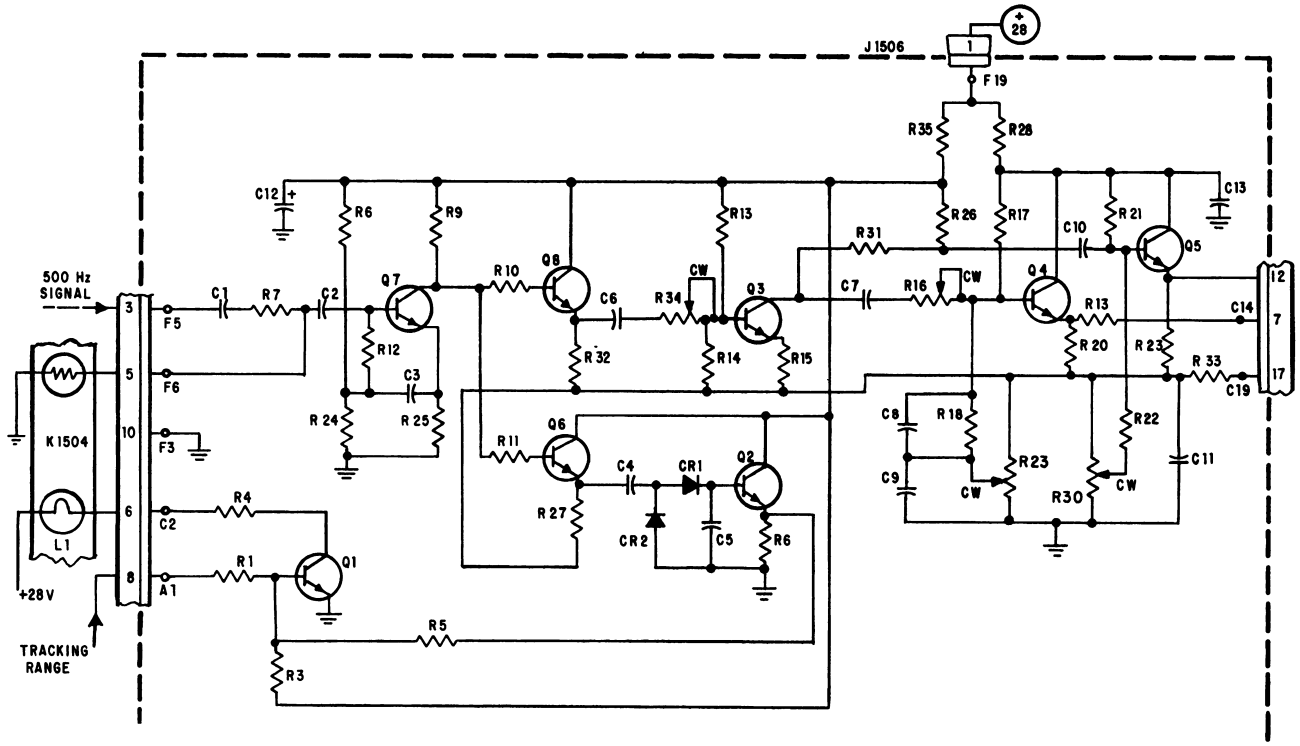

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Figure 11-35 —Range circle generator.

The range circle generator (fig. 11-35) provides two sine-wave signal outputs 90° out of phase with each other. The amplitudes of each signal is controlled by a d-c range signal from the tracking unit. Inputs to the circle generator are a 500-Hz reference signal and the d-c range voltage from the tracking unit. The 500-Hz signal is applied to amplifier transistor Q7 through capacitors C1 and C2 and resistor R7. Resistor R7 is part of a voltage divider consisting of R7 and a resistor contained in raysistor K1504 (a raysistor is a series of switching devices, the output consisting of a photoresistor which may be excited by various forms of electrical lights). Resistance of the raysistor resistor varies with the intensity of the raysistor light L1.

Output for transistor Q7 is applied to signal emitter follower Q8 and to feedback emitter follower Q6. The output of Q6 is rectified by the action of diodes CR1 and CR2 to obtain a positive voltage whose amplitude is proportional to the a-c signal. This positive voltage is applied through emitter follower Q2 and resistor R5 to transistor Q1. Also applied to transistor Q1, through resistor R1, is the d-c range voltage. The resulting effect is a voltage on the base of Q1 that is proportional to the d-c range voltage and the d-c feedback voltage. The output of Q1 varies the intensity of L1, which in turn varies the resistance of the raysistor resistor. Therefore, the resistance of R1504 is proportional to the output of Q1. This directly controls the amplitude of the output of Q7, since it is part of its input voltage divider. Thus the output amplitude of Q7 is controlled by the d-c tracking range input voltage to Q1. The output of Q7 is applied to emitter follower Q8, then on to buffer amplifier Q3 through potentiometer R34, which ultimately adjusts the diameter of the displayed circle.

Two outputs are taken from transistor Q3. One is applied through a lagging phase shift network consisting or potentiometer R16 and capacitor C8 to emitter follower transistor Q4; the other is applied through leading phase shift capacitor C10 to emitter follower transistor Q5. Thus, the outputs of Q4 and Q5 are 500-Hz sine-wave voltages phase-shifted by 90° with their amplitudes controlled by the d-c range voltage. Potentiometer R16 provides a fine adjustment of the phase shift. These two outputs, 90° out of phase, are applied to the deflection amplifiers to produce a circular trace on the cathode-ray tube.

MICROELECTRONICS

The trend toward miniaturization began with the development and subsequent use of the transistor and the solid state diode. These devices tremendously decreased equipment weight and bulk. For example, the weight of airborne navigation and communications equipment decreased as much as 50 percent during the first decade of transistor use, and the reduction in bulk was even more spectacular—transistors permitted the computer to go airborne.

However, it was not until the development of solid state devices reached the point where truly integrated circuits were a reality that a new plateau was reached and a breakthrough from miniaturization to microminiaturization was achieved. In the near future, microminiaturization—or microelectronics as it is now termed—promises an almost unbelievable reduction in size and weight, with an increase in reliability and lower lifetime costs.

Lifetime cost (the cost of the initial equipment plus the cost of maintaining it in operating condition) is an important factor economically and operationally. High reliability and good maintainability are prerequisites to low life-time costs; both are inherent in the microelectronics program.

MICROELECTRONIC TERMINOLOGY

Each time a new development appears in any field there are usually new descriptive terms and phrases to describe or explain the new methods and devices.

In the new field of microelectronics there has also evolved a new terminology. Although the definitions of the new terms have not yet become precise, and some no doubt will be changed, a few of the more common presently in use are listed below:

1. Active device—A component displaying gain or control such as transistors, diodes, or vacuum tubes.
2. Passive device—A component displaying no gain or control such as resistors, capacitors, inductors, etc.
3. Discrete component—Individual nonintegrated active or passive components. Includes all components listed in 1 and 2 above.
4. Thin film circuit—A network of passive devices and interconnections formed in thin layers on a nonconducting substrate (base) by spray, vapor, or sputtering process.

5. Substrate—The physical material upon or within such a circuit if fabricated.

6. Integrated circuit—A number of active and/or passive devices formed on or within a continuous body or substrate (usually silicon semiconductor) and interconnected with deposited metal patterns to perform a given function.

7. Hybrid circuit—A packaged circuit consisting of a combination of one or more integrated circuits and/or discrete components or thin film devices, used to achieve a given function.

PURPOSE

The primary purpose of this new trend in electronics is to develop building blocks, with each block performing the function of a circuit or a system, which will accomplish the following objectives:

1. Perform more electronic functions per unit of volume, weight, cost, power input, and power dissipated than is possible with the most advanced presently available components and circuit assembly techniques.
2. Possess considerably higher reliability than their conventional counterparts which will reduce maintenance to a minimum.
3. Be low priced, making "throwaway maintenance" economically feasible.
4. Perform new functions not possible with present components.

Size reduction alone is not always the aim of microelectronics. Although small size and reduction in weight are very important in many cases, there are applications where these characteristics are not important enough to justify the time and expense to develop an entirely new form of systems fabrication. The reduction in size in this technology is an inherent feature.

TECHNIQUES

Basic techniques and materials to design and fabricate a limited number of microelectronic circuits are now available. However, additional extensive research and development are required to provide suitable materials and techniques to satisfy the demand for other circuits and for improved performance and reliability at a reasonable cost.

The thin film microelectronic process is based on fabricating complete functions or circuits by depositing thin films on substrates. The various elements of the circuits, therefore, cannot be disconnected from each other. The method most generally used in fabricating the thin film circuit is to evaporate a metal or dielectric in a high vacuum and condense the vapor on a thin, inactive support wafer or base (substrate). Carefully prepared masks are used to control the areas on which these metals or dielectrics are deposited. Presently, resistors, capacitors, and conductors can be deposited quite conveniently. Note that the components are still referred to, the same as they were in the past. The differences are that there are no component leads and that the interconnections are an integral part of the circuit.

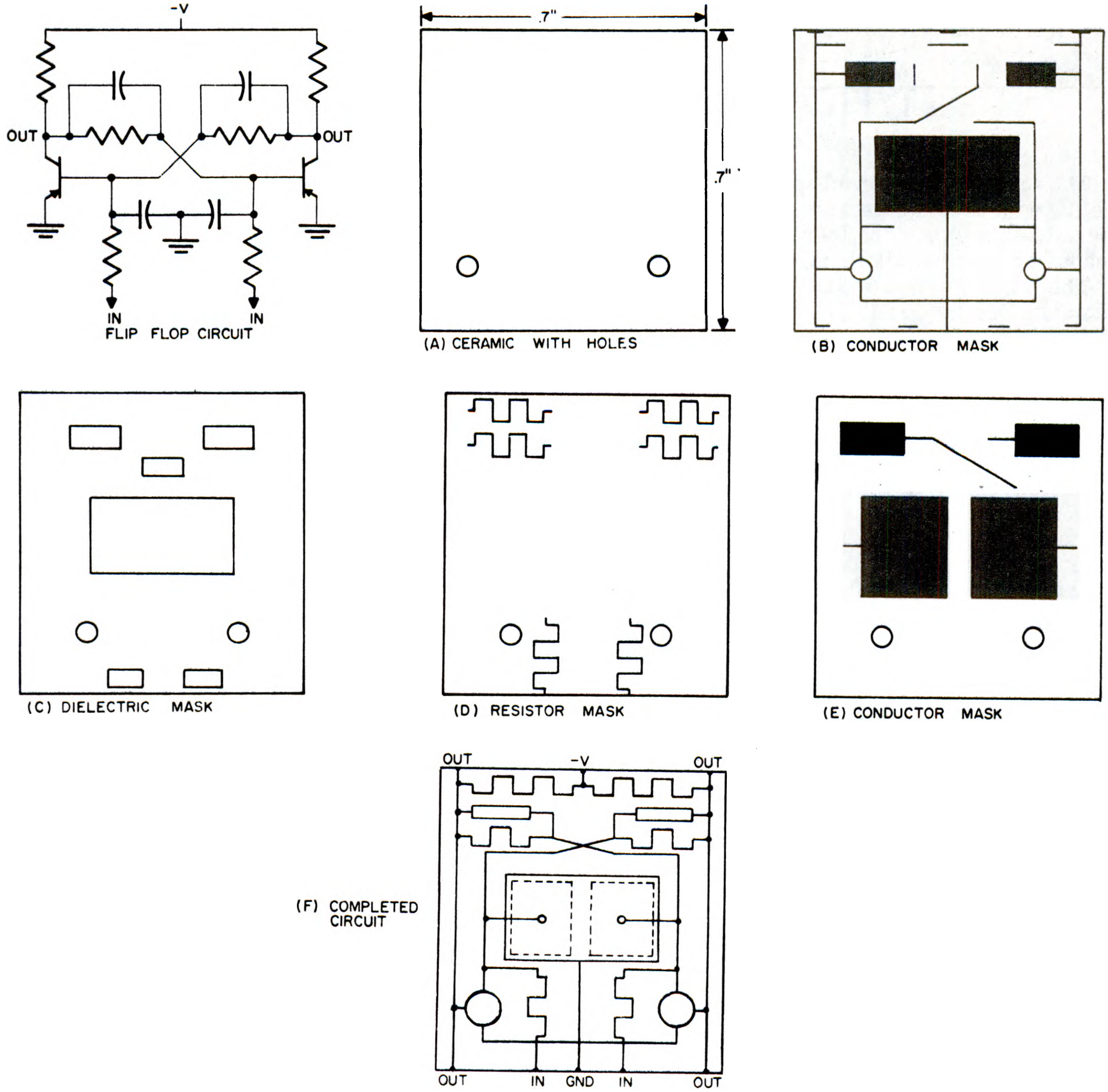
The basic advantage of this technique are the high density of the components, the sharp decrease in the number of connections, and the replacement of soldered and mechanical connections by the more intimate ones formed at the time the material is deposited. Some of the problems that remain are heat dissipation, interconnections between circuit wafers, and stability of the components during and following the "packaging" of the circuits. Still lacking is a technique for depositing active elements. Such a technique would be a major improvement over present methods in which the active element is produced separately as a discrete component and inserted into the thin film circuits.

Figure 11-36 shows the basic steps in fabricating a simple thin film, flip-flop circuit. The original substrate (A) has two drilled holes to accommodate the transistors. The mask used when the conductors and one of the two electrodes for each of the four capacitors are deposited is shown in figure 11-36 (B). The capacitor dielectrics and crossover insulation points and then deposited (C). The resistor mask is shown in figure 11-36 (D), and the mask for the second electrode of each of the four capacitors is shown in (E). The complete wafer is shown in (F).

APPLICATIONS

The following are but a few examples of the many microelectronic applications presently in use or being developed for naval aviation.

An air-sea rescue transceiver unit has been produced which provides two-way voice communication and transmits a beacon signal for a



FLIP FLOP CIRCUIT

(A) CERAMIC WITH HOLES

(B) CONDUCTOR MASK

(C) DIELECTRIC MASK

(D) RESISTOR MASK

(E) CONDUCTOR MASK

(F) COMPLETED CIRCUIT

Figure 11-36.—Fabrication of a thin film, flip-flop circuit.

continuous period of 24 hours. This entire unit weighs three-fourths of a pound and requires 8.4 cubic-inches of space (a little larger than a package of cigarettes).

The Loran C Navigation Set was reduced in weight by approximately 100 pounds with the use of about 900 microcircuits. Reliability of this particular equipment was increased nearly five-fold and space requirement was reduced by 1.25 cubic feet. Other equipments include computers, missiles, fuzes, and other ordnance devices.

CHAPTER 12

TYPICAL WEAPONS CONTROL RADAR

The purpose of this chapter is to acquaint the AQ with a complete radar system which is operationally typical of those found in modern weapon system installations.

This radar system is the Radar Maintenance Trainer Device 11D13A. This system was selected because an actual operational system would require that much classified information be included. Since the trainer is different from an operational system in some respects, these differences are noted, if in so doing, it does not violate security of classified information.

The device 11D13A includes all the elements essential for basic search radar ranging: A transmitter, receiver, antenna, and synchronizer circuits. Additional elements including tracking, stabilization, and target generation (simulated targets) allow operation as either fire control (intercept) or bomb director radar. The target generator unit, although not typical of operational radar systems, produces and controls the target in a manner typical of analog computing systems. It contains both mechanical and electronic elements found in analog computing systems. A block diagram of the trainer is illustrated in figure 12-1.

MODES OF OPERATION

The trainer 11D13A is capable of operating in three basic modes which are then divided into submodes. These submodes parallel the general modes in actual weapons control systems. The three modes available in the trainer are search, fire control, and bomb director.

The trainer has no standby mode as such. (The purpose of the standby mode is to apply filament voltages for initial warmup before selecting an operating mode.) Most radar sets include an automatic timein (time delay) circuit which prevents application of power to the high voltage sections prior to the necessary warmup period.

The term acquisition, as used in operation of a radar set, refers to a momentary mode of operation. The time period for acquisition begins at the moment the operator depresses a control switch transferring antenna control from automatic search to manual search. During this period the operator has complete control of antenna position, both in azimuth and elevation. He may also control a symbol on the indicator called an acquisition symbol. By placing the acquisition symbol over the selected target, coincidence between the tracking gate and the target is accomplished in the range and tracking circuits of the radar. Acquisition is complete when lockon occurs and the system switches to automatic track.

SEARCH MODE

Search operation for airborne and ground targets is provided with ranges of 0 to 6,000 yards and 0 to 12,000 yards. In this mode the antenna automatically scans the horizon, rotating in either direction up to 6 rpm. Manual control of the antenna in this mode provides manual tracking of detected targets. There is some minor difference in the method of manual control; however, this difference is of little consequence and will be noted at the appropriate time. Range marks are selectable in 1,000-, 2,000-, or 3,000-yard increments, although actual weapons control radar will have much longer ranges. In the basic search mode, the B-scope, which is also included in the indicator unit, is deactivated.

FIRE CONTROL MODE

When the fire control mode is selected, the target simulator provides a three dimension target (target with range, azimuth, and elevation information). In the fire control mode there are five submodes: automatic search, manual search, acquisition, automatic track, and breakaway. These five submodes permit the simulated target to be detected initially, manually tracked and acquired, and tracked automatically until minimum range is reached. At this time, a breakaway signal in the form of an X is displayed on the B-scope indicator, warning the operator to break away from the target. In an

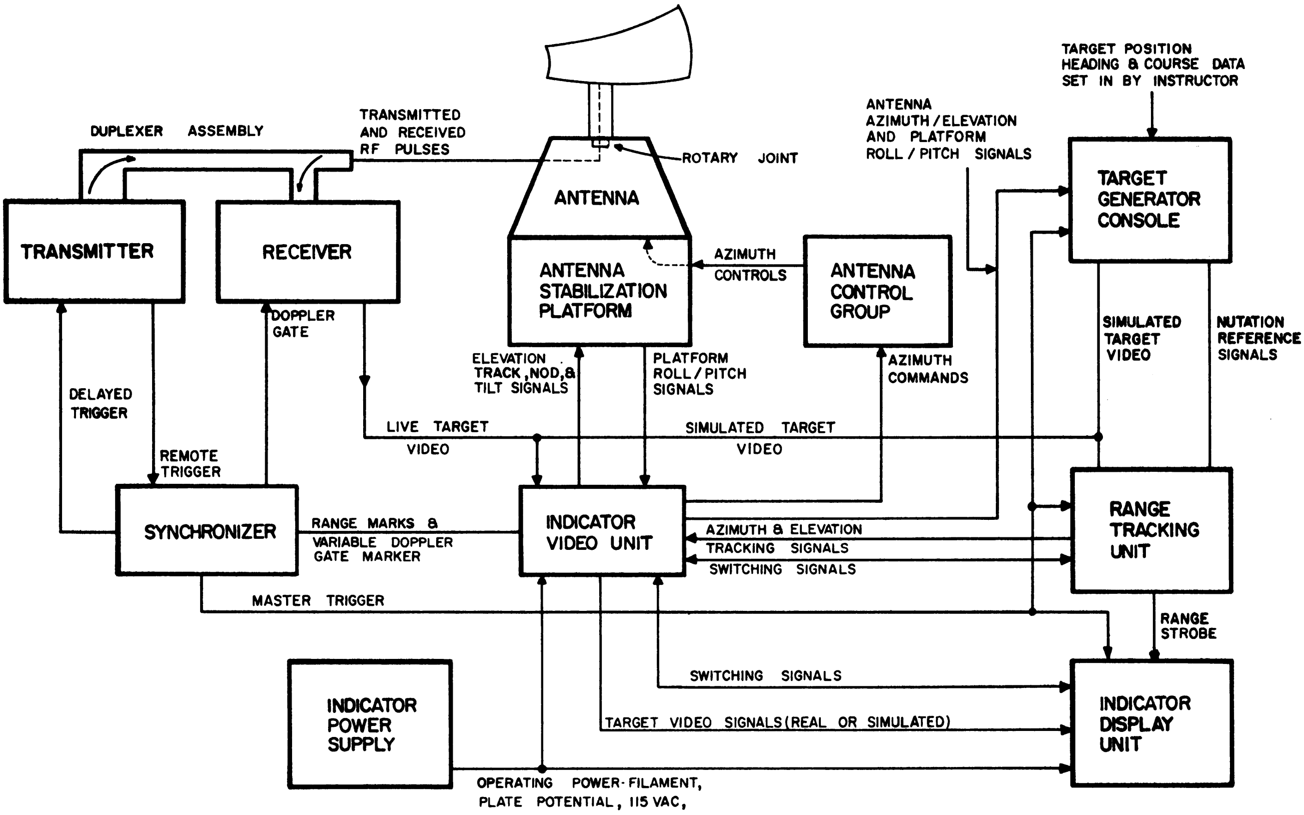

DUPLEXER ASSEMBLY
TRANSMITTED AND RECEIVED RF PULSES
ROTARY JOINT
ANTENNA AZIMUTH / ELEVATION AND PLATFORM ROLL / PITCH SIGNALS
TARGET POSITION HEADING & COURSE DATA SET IN BY INSTRUCTOR
TRANSMITTER
RECEIVER
ANTENNA
ANTENNA STABILIZATION PLATFORM
AZIMUTH CONTROLS
ANTENNA CONTROL GROUP
TARGET GENERATOR CONSOLE
DOPPLER GATE
DELAYED TRIGGER
REMOTE TRIGGER
ELEVATION TRACK, NOD, & TILT SIGNALS
PLATFORM ROLL / PITCH SIGNALS
AZIMUTH COMMANDS
SIMULATED TARGET VIDEO
NUTATION REFERENCE SIGNALS
LIVE TARGET VIDEO
SIMULATED TARGET VIDEO
SYNCHRONIZER
RANGE MARKS & VARIABLE DOPPLER GATE MARKER
INDICATOR VIDEO UNIT
AZIMUTH & ELEVATION TRACKING SIGNALS
SWITCHING SIGNALS
RANGE TRACKING UNIT
MASTER TRIGGER
RANGE STROBE
SWITCHING SIGNALS
INDICATOR POWER SUPPLY
TARGET VIDEO SIGNALS (REAL OR SIMULATED)
INDICATOR DISPLAY UNIT
OPERATING POWER-FILAMENT, PLATE POTENTIAL, 115 VAC, CRT ACCELERATOR VOLTAGES

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Figure 12-1.—Trainer 11D13A functional block diagram.

actual weapons radar, the X also means that the aircraft is too close to the target to allow time for an air-to-air missile to properly track the target.

Minimum range in fire control operation is 3,500 yards. Three ranges are provided for target information while operating in the fire control mode—0 to 10,000, 0 to 40,000, and 0 to 80,000 yards. During this mode of operation, target information is displayed on both the PPI and B-scope of the indicator display unit. The B-scan display uses a dual-gun arrangement (to be discussed later) which provides steering information in addition to the normal plot display.

BOMB DIRECTOR MODE

Operation in the bomb director mode covers the same ranges provided in the fire control mode. Aiming data are displayed on both the PPI and B-scope displays. Switching circuits, which are energized at the time of mode selection, cause the presentations to be altered to conform to typical bomb director system presentations. The PPI display has a depressed-center sector scan at twice the scale of the fire control mode, and the B-scan reflects the target area at five times the scale of the PPI. Both indicators include controllable range and azimuth marks (strobes) which act as crosshairs to facilitate aiming (aim point tracking).

SYSTEM CONTROLS

Through the manipulation of the basic controls, the operator has available all of the previously mentioned modes of operation. The controls of the trainer are decentralized to simplify construction and operation, but these controls can be grouped into five major categories according to their function. The five major control functions are:

1. Power switch.
2. Mode switch.
3. Receiver gain control.
4. Antenna azimuth and elevation control.
5. Range control.

POWER SWITCH

The power switch is the system's off-standby-operate switch and may have several positions of operate. The off position, of course, removes all power from the system. The standby position, as previously described, applies filament power, and keep-alive voltage to the TR tubes. For purposes of training, the 11D13A has a power switch for each of the major units (antenna, transmitter, etc.). This allows for operation of each of the units or any selected combination of units for training. During the discussion throughout this chapter, the appropriate control will be noted along with its function and the relation to one of the four major function controls, if necessary.

MODE SWITCH

The mode switch is practically self-explanatory. In the trainer, this switch sets up one of the basic operating modes available, such as search, bomb director, or fire control.

RECEIVER GAIN

The receiver gain control is one of the most important controls available to the operator, whether he be the pilot in an aircraft or an operator on a trainer. This control, if not properly adjusted, will prevent the entire system from operating at peak performance. Some radar systems include a built-in test function which provides a reasonable check of the adjustment of the receiver gain control. This control is normally adjusted for best definition of the weakest target available. To obtain peak detection (which provides maximum range) there is only one acceptable method for adjusting this control. In each particular radar this method is part of the minimum performance test.

ANTENNA CONTROLLER (HAND CONTROL)

The hand control of an actual radar installation allows the operator to select manual search operation, and also allows selection of targets. Through the use of this control he may command the radar to acquire and/or release the target.

During automatic search, this control has but one function. This is to position the antenna in elevation to select the area to be searched in relation to the horizon. It can be seen that this control and the receiver gain control are very important in that they will affect target detection performance.

During manual search the hand control has complete control of the antenna and in addition also controls the acquisition symbol to acquire the target.

AUXILIARY CONTROLS

Through the use of a scan switch in an operational radar, the operator may select either full azimuth or sector scan. The trainer likewise incorporates a scan switch, which may be used to select the type of scan desired. In the trainer the selections are automatic sweep at a 6 rpm rate, variable sweep from zero to 6 rpm manually controlled, or sector scan.

INDICATOR DISPLAYS

A description of the indicator displays (PPI and B-scope) in the three basic modes of operation and the submodes of fire control is given in the following paragraphs. The information on the indicators allows this system to simulate operation in all weather conditions.

BASIC SEARCH

In the basic search mode, information is displayed on the PPI only. As shown in figure 12-2, the PPI scan presentation may be a map-like picture of the earth's surface being scanned. The range sweep line rotates in synchronization with the antenna through a full 360° cycle. Targets appear on the face of the CRT as an intensified light spot. The range of the target is indicated by its position on the radius of the range sweep line, and target azimuth position is indicated by the angle of the sweep line at the time the target is painted. The top of the scope is 0° and may indicate dead ahead.

If 1,000 yard-range marks are selected, then the two range marks shown in the figure are 1,000 yards apart. Starting from the center of the scope and moving outward toward the edge of the scope face, the first range mark then indicates targets from zero to 1,000 yards. In the figure there are two targets shown that are between the 1,000- and 2,000-yard marks. Other targets are illustrated at greater ranges and at different azimuth positions. The presentation

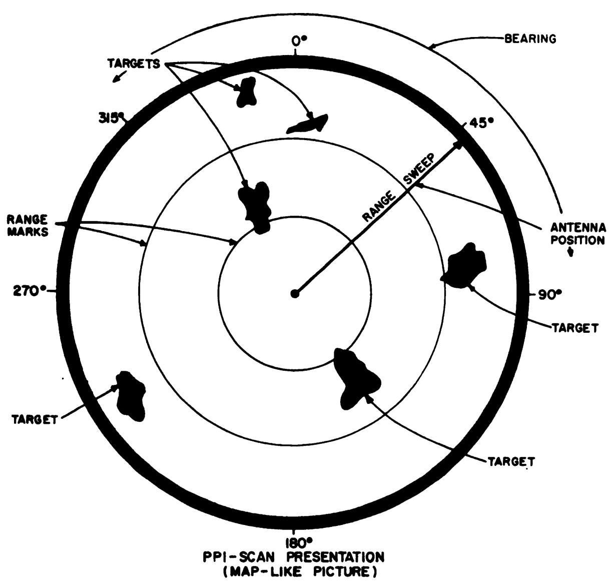

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Figure 12-2.—PPI scan presentation basic search.

illustrated could be a ground map of an area of the earth's surface showing several islands. The shape of the target appearing on the scope will be very nearly the actual shape of the target as viewed visually. If, however, the antenna were scanning above the horizon, an airborne target would be a very small bright spot and target shape would not be defined.

FIRE CONTROL (AUTOMATIC SEARCH)

In the automatic search submode of fire control, information is displayed on both indicators. The PPI presents target range and azimuth information as before. Now, the B-scope also presents information that, if the system were operating in an aircraft, would be required to make a successful attack on an airborne target. This information is illustrated in figure 12-3.

In figure 12-3, which is a normal B-scan search display, four items of interest are painted electrically on the face of the CRT. The first is the range sweep line, sometimes referred to as the B-trace. This time, however, the sweep is from the bottom of the scope to the top. Range on a B-scope is measured from the bottom of the scope to the top. The length of the trace then is equal to the range selected. If the 0- to 10,000-yard range is selected, the length of the range sweep line is 10,000 yards. The position of the sweep line on the face of the scope, as was the sweep line on the PPI, indicates the azimuth position of the antenna. The trace scans back and forth following the antenna.

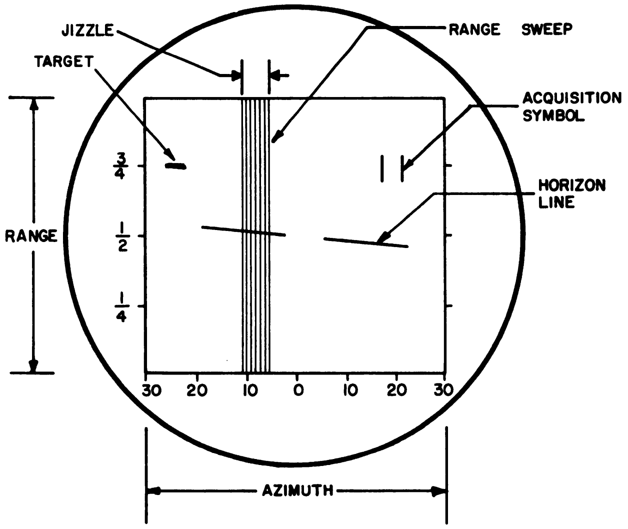

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Figure 12-3.—B-scan presentation in automatic search.

It should be noted that the scan line is not a single line, but is made up of several lines, causing it to become quite wide; this is called "jizzle" and is the result of simulated antenna spin modulation, as described in chapter 6. In an actual radar system, this is accomplished by nutation of the antenna feed horn or reflector dish. In the trainer a scan generator produces the effect of the antenna nutation but the antenna is not actually nutated. Figure 12-4 (A) illustrates an antenna pattern which is simulated in the trainer. Note also in part (B) of the figure that there is a box like pattern produced. This is accomplished by introducing a nod at the ends of the scan.

The second item on the scope is video (targets). As the antenna scans back and forth, any target within range of the radar appears as a bright spot on the face of the CRT. The range of the target will be indicated by its vertical distance from the bottom of the scope. The azimuth position of the target is indicated by the position of the target either to the left or to the right of the center. For example, if the target appears as shown in figure 12-3, its range is

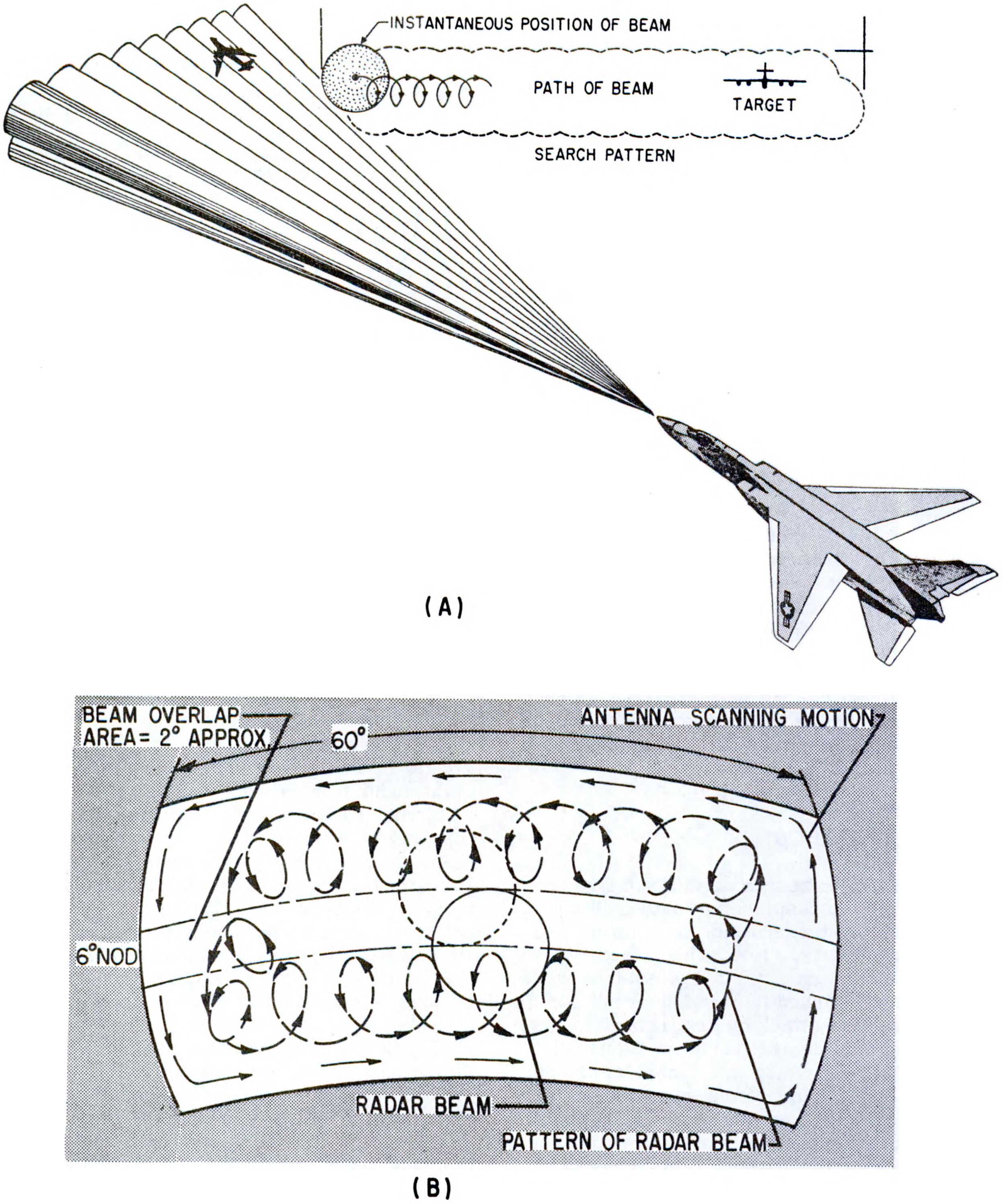

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Figure 12-4.—(A) Antenna scan pattern; (B) antenna coverage pattern.

7,500 yards (on the 10,000-yard range scale) and is to the left of the attacking aircraft. Most radars installed in fighter type aircraft also have an indication of the antenna tilt which is used to indicate elevation position of the target relative to the attack aircraft. If the target were above the attacking aircraft, the antenna would have to be tilted up in order to receive a target echo. The amount of tilt can then be read from the indicator, and the pilot may steer his aircraft accordingly to intercept the target.

The third item on the B-scope, is the acquisition symbol. During automatic search, the acquisition symbol is relatively unimportant but is movable and could be used to mark the area of target return. The symbol, as shown in figure 12-3, is made of two short vertical lines separated slightly. Position of the symbol in the vertical indicates range, and is controlled by the range circuits, which in turn are controlled by the hand control in an actual radar system. Movement of the hand control back or forward decreases or increases range voltage which causes the acquisition marks to move in or out in range. The acquisition marks are also controllable in azimuth, by movement of the hand control either to the left or to the right. Therefore, the acquisition marks may be positioned anywhere on the face of the scope. This is described in greater detail later.

The fourth symbol on the face of the scope is the artificial horizon line. This symbol is a straight line with the center blanked out and is positioned horizontally on the face of the indicator tube. The purpose of the horizon line is to indicate aircraft attitude. In automatic search the horizon line represents the earth's horizon and when the aircraft rolls or pitches, the artificial horizon banks or moves up or down in accordance to aircraft movement. This movement of the horizon line is controlled by outputs from the aircraft vertical gyro or stable platform.

FIRE CONTROL (MANUAL SEARCH)

Manual search allows the operator to stop the antenna from scanning, and direct it toward any desired target which had been detected during automatic search. Tilt or elevation control of the antenna which was provided in automatic search is still available in manual search. In addition, control of the antenna in azimuth is now available. In the operation of an actual radar installation, control of the antenna in both elevation and azimuth is a function of the hand control. In the trainer, however, azimuth and elevation controls are separate. The provision of separate controls is of no great significance, except for convenience of operation.

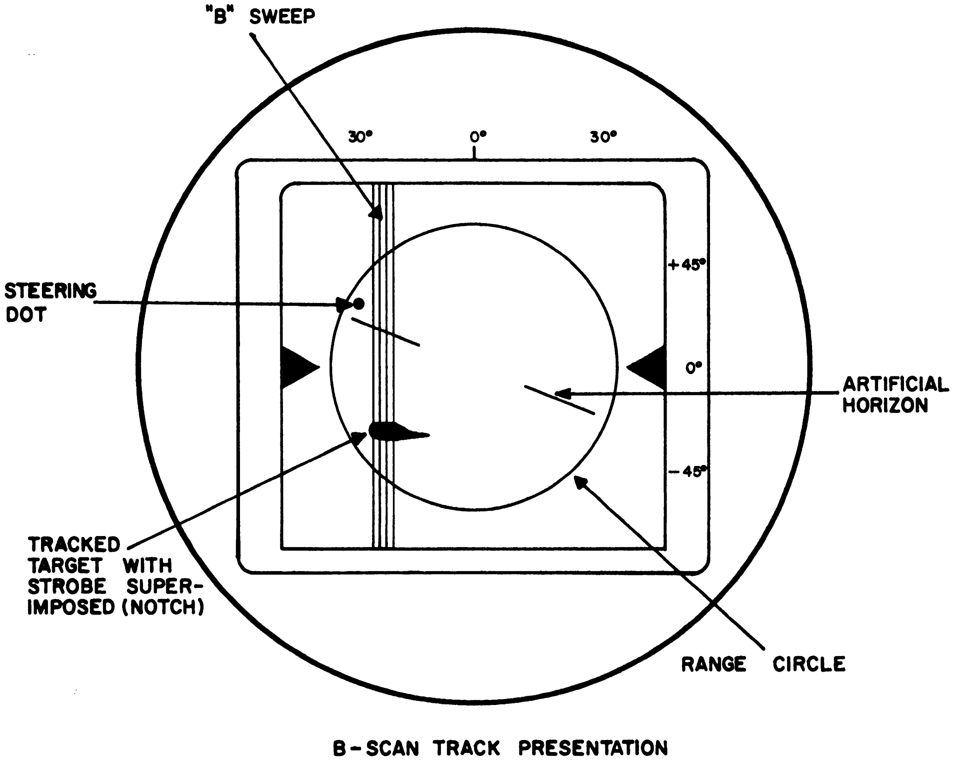
When manual search is initiated, the acquisition marks move to bracket the range sweep line (B-trace) and both the B-trace and the acquisition marks move together in azimuth. The position of the acquisition marks in range is also available in the manual search mode. This allows them to be positioned anywhere on the B-trace from zero to maximum range, depending on the range selected. For example, if the radar is operating in the 0- to 10,000-yard range, and a target appears at 5,000 yards, the acquisition marks may be moved to bracket the target by use of the range control.

The major display differences, then, between automatic search and manual search are that the acquisition marks bracket and move with the B-trace, and the antenna is controllable in azimuth. All symbols that were present in automatic search, including the artificial horizon, are present in manual search. The horizon line still functions to indicate aircraft attitude. It should also be reasonable to expect to see no targets other than the ones which appear on the range sweep line, since the antenna is no longer scanning.

FIRE CONTROL (LOCKON)

The lockon mode is a momentary mode of operation between manual track and automatic track. Some radars include the previously described manual operations and the lockon mode in one mode called acquisition. Recall that acquisition is the period of time from the moment the antenna stops scanning until the radar locks on and begins to track the target automatically. However in the trainer, manual track may be continued after lockon, if desired. Lockon is known to have been accomplished by a change in the B-scope presentation, and the blanking of the PPI scope. The changes which take place are described in the following paragraphs.

The acquisition symbol is removed and replaced with a range strobe or notch superimposed on the target, as shown in figure 12-5. The artificial horizon remains as before. Note, that there are two symbols present now that were not present previously. One of these is a small dot, called a steering dot. The purpose of the


"B" SWEEP
30°
0°
30°
+45°
0°
-45°
STEERING DOT
ARTIFICIAL HORIZON
TRACKED TARGET WITH STROBE SUPER-IMPOSED (NOTCH)
RANGE CIRCLE
B-SCAN TRACK PRESENTATION

AQ.475

Figure 12-5.—B-scan presentation after lockon.

steering dot is to indicate antenna position which also presents target position with respect to the attacking aircraft. For a pure pursuit course the pilot need only maneuver his aircraft to cause the steering dot to remain in the center of the scope. When the steering dot is in the center of the scope on a pure pursuit course, the target is dead ahead of the attacking aircraft.

The second symbol which was not present in the previous modes is a circle. This circle is called the range circle, and its diameter will be proportional to range. Normally, lockon occurs at near maximum range which will produce a range circle of maximum size. As the range between the attacking aircraft and the target decreases, the diameter of the circle also decreases keeping the operator informed of the range to the target. In addition to these symbols, two other indications of range are presented at the time the radar locks on. A light, called the lockon light or acquisition light, is illuminated when the target has been acquired and lockon has, in fact, been accomplished. Range is also presented in digital form in a small window similar to the mileage counter of an automobile.

FIRE CONTROL (AUTOMATIC TRACK)

The automatic track submode of fire control results from the manual track mode upon release of the manual controls (range and azimuth). Remember, prior to automatic tracking the antenna had been manually controlled in both elevation and azimuth and the range strobe (notch) had been controlled by the range control. To initiate automatic tracking the operator releases the manual controls and the radar switches to automatic track. At this time the antenna is caused to track the target by the antenna servo-system error circuits.

Range tracking is accomplished in the range tracking circuits. Automatic tracking continues until one of three things occur. First, lockon will be lost if the attacking aircraft is closing on the target at a rate greater than 700 knots, or if an opening rate greater than 200 knots should occur. Second, the target will be lost and the radar will unlock if the target does not remain within the tracking window (antenna limits in azimuth and elevation). Of course the target will be lost if the range exceeds maximum tracking range. Maximum range for tracking is 40,000 yards. At ranges beyond 40,000 yards the return echo will be too weak to maintain lockon. If unlock occurs, the system is automatically returned to automatic search and the cycle of manual track and acquisition must be repeated to regain target tracking.

FIRE CONTROL (BREAKAWAY)

The final submode of fire control is known as breakaway. This mode occurs automatically if the target is tracked to a range which would endanger the attacking aircraft. During automatic track of a target which has a decreasing range (attacking aircraft is closing on the target), the range circle is removed at the time the range to the target gets to 3,500 yards. In its place is displayed a large "X" which indicates time to break away from the attack. (See fig. 12-6.) Also, at this time the steering dot will move to a position on the scope to indicate the safe direction for the attacking aircraft to turn in order to execute a safe breakaway. In the illustration minimum range has been reached and the breakaway X has appeared. The steering dot is presently positioned to the right and above center.

BOMB DIRECTOR MODE

When bomb director mode of operation is selected, information is displayed on both PPI and B-scope indicators. In this mode the antenna automatically goes to sector scan, scanning a 60° arc, 30° to each side of dead ahead. Antenna elevation is manually controlled. The PPI scope has a depressed center which appears as a wedge shape scan on the indicator face, as shown in figure 12-7. The antenna would be positioned in elevation so that it will scan the surface of the earth during a bomb attack.

The target tracking range and azimuth strobes appear on each of the two indicators and are moved manually so that the marks form a crosshair effect and are centered over the target to be tracked. Tracking is maintained manually in the bomb director mode. The B-scan presentation which is expanded to five times that of the PPI is used for precise aiming. The azimuth and range strobes are controllable from 0 to 80,000 yards, and in azimuth 25° to either side of center.

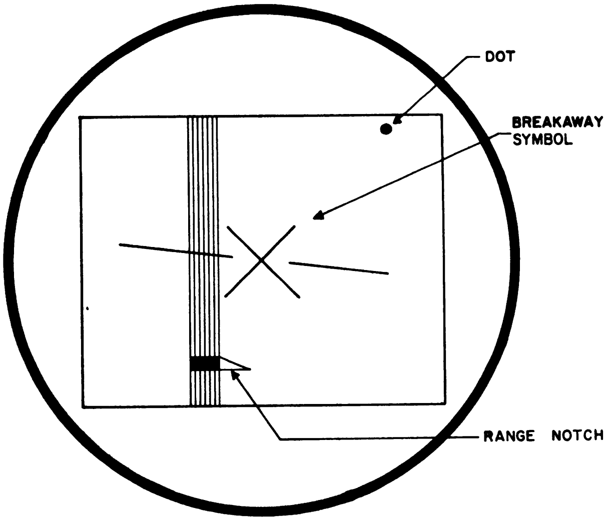


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Figure 12-6.—B-scan presentation breakaway indication.

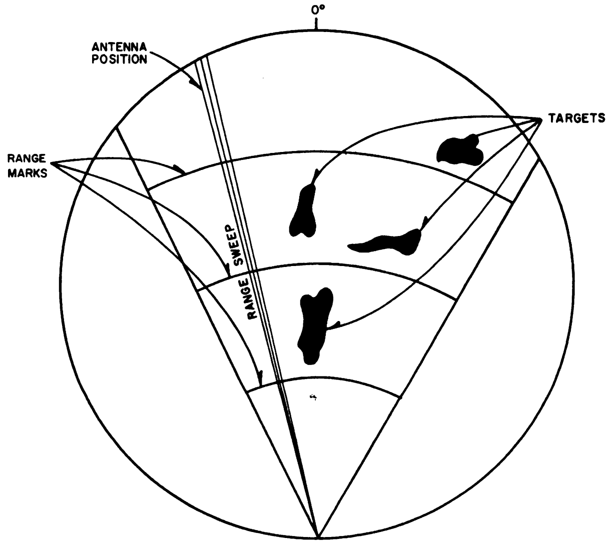

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Figure 12-7.—PPI presentation in bomb director mode.

THEORY OF OPERATION

The theory of operation of the trainer 11D13A is described in the following discussion. Block diagrams are presented for each of the main units, and circuit tracing is avoided since most of the circuits, typical of an operational radar, were described in other chapters in this course.

SYNCHRONIZER

The synchronizer develops all of the timing signals required for proper operation of the radar in all modes. Functionally the stages which comprise the synchronizer are grouped according to the signals they develop, as shown in figure 12-8. Table 12-1 lists and describes the nature of these outputs. Inputs to the synchronizer are the a -c operating power and the remote trigger from the transmitter.

Timing Signal Generation

The timing sequence of the synchronizer is initially controlled by a 1-kHz reference oscillator. The basic timing signal is developed by the reference oscillator and is then coupled to the Schmitt trigger stage. The trigger stage produces sharply defined, stabilized, negative square waves which are differentiated in the output and then coupled to the emitter follower. The emitter follower provides isolation between the trigger stage and the delay, and master trigger circuits. The purpose of the isolation is to prevent loading of the trigger stage. The output of the emitter follower is a series of negative pulses which have been clamped at ground potential and occur at a precise 1-kHz repetition rate. Note that these pulses have very sharp leading edges that correspond to system time zero, t_0.

From the basic trigger circuit the timing pulses are coupled into the master trigger circuit which serves to increase pulse power. After the pulses are amplified, they are inverted to produce positive pulse trains and are again clamped at ground potential. These pulses, which are in coincidence with those of the basic trigger circuit, are used to maintain synchronization of the indicator, range tracking circuits, and target generator with the rest of the system.

Referring again to figure 12-8, note that the same basic trigger is also applied to the delay circuit. The purpose of this circuit is to produce pulses which are used to trigger the transmitter during the time the synchronizer is controlling the PRF. The input pulses are applied to a delay multivibrator. The output of this multivibrator is a positive going pulse train whose leading edges are coincident with the input, but whose trailing edges may be adjusted (delayed) in a range from 2 to 6 μsec. The pulse train is first amplified in the trigger amplifier and inverted. The output of the trigger amplifier is a negative going pulse train, which is applied to a blocking oscillator. The blocking oscillator is triggered by the positive swing (trailing edge) of the pulses applied. Since the trailing edges are adjustable, the time that the blocking oscillator is triggered may be varied and its output will be a positive going pulse train whose leading edge may appear (in time) anywhere from 2 to 6 μsec later than the input time zero pulse. This is illustrated by the waveform at the output of the delay circuit.

Recall that range marks appeared on the PPI sweep at intervals of 1,000, 2,000, or 3,000 yards. To insure that these marks appear at the correct time and indicate correct range on the sweep, the range marks circuit must be triggered at the time the transmitter fires. Note in the illustration that the range marks circuit may be triggered either by the delayed trigger or by the remote trigger from the transmitter. The selection of the trigger to be used is the function of the local-remote switch S1. Assuming the local-remote switch to be in the local position, the range marks circuit will be triggered at the same time the transmitter is fired (using the output of the delay trigger circuit).

Generation of the range marks is initiated by the application of the delayed trigger pulse or remote trigger from the transmitter to a ringing oscillator. This oscillator produces a 162-kHz sinusoidal output which is coupled into an emitter follower and then to a countdown multivibrator. The operation of the countdown multivibrator is controlled by the range marks selector switch, which determines whether the marks are 1,000-, 2,000-, or 3,000-yard marks. The output of the circuit is shown as a pulse train in coincidence with the delayed or remote trigger. The time between pulses (P) is determined by the setting of the range marks switch. The output is next applied to a marks mixer where it is mixed with a Doppler marker and routed to the indicator.

The Doppler gate, which is required by the receiver for operation of the sensitivity time

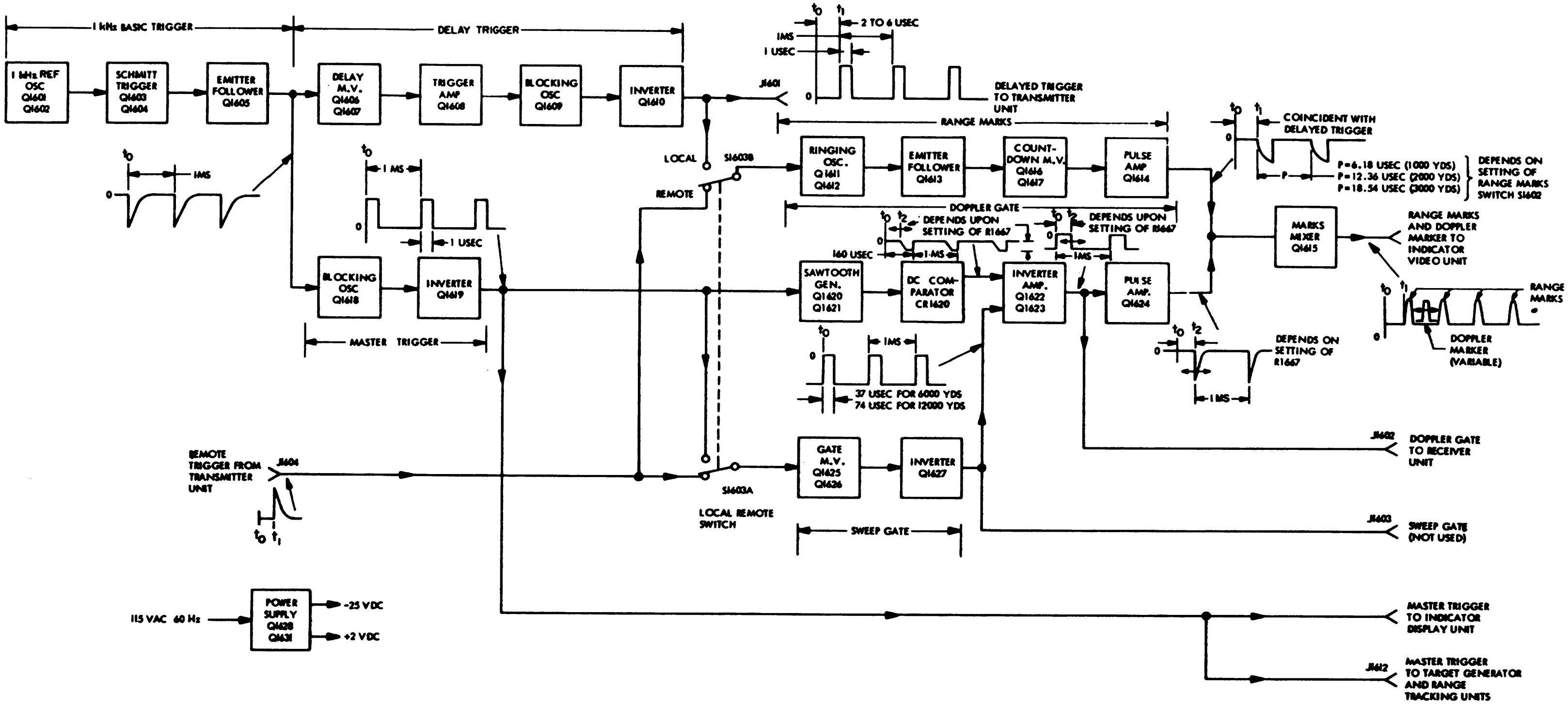

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Figure 12-8.—Synchronizer functional block diagram.

Table 12-1.—Synchronizer signal description and function

Signal	Description and function
Master trigger	20-volt, positive, ground-clamped, 1- μsec pulses occurring at a repetition rate of 1-kHz. The leading edge of the master trigger pulses establishes time zero for the entire system. These pulses are applied directly to the indicator display (unit 1500) target generator (unit 1300) and range tracking (unit 1900) chassis to insure proper synchronization between the three.
Delayed trigger	20-volt, positive, ground-clamped, 1-μsec pulses occurring at a rate of 1-kHz. The leading edge of the delayed trigger pulses is adjustable in time over a range of 2 to 6-μsec after the master trigger pulses, and serve as a transmitter trigger pulse, allowing coincidence between the PPI sweeps and displayed target video to be adjusted to compensate for overall system delays.
Range marks	20.5-volt, positive, ground-clamped pulses occurring with an interpulse time of 6.18, 12.36 or 18.54 μsec depending upon the setting of the 1,000-, 2,000-, 3,000-yard range selector switch S1602. Timing is adjustable to be coincident with the leading edge of the master trigger pulse or the remote trigger pulse depending upon the position of the LOCAL-REMOTE switch S1603. Range marks are applied to the PPI scope in the 6,000- and 12,000-yard search modes of operation only.
Doppler gate	Variable width, 25-volt, negative pulses occurring at a 1-kHz rate, timed so leading edge develops at time zero. Leading edge serves as a trigger for the receiver unit STC circuit, and the variable trailing edge serves to trigger the receiver Doppler gate circuits. Trailing edge also is differentiated to form a Doppler marker pulse which is mixed and applied to the PPI with the range mark pulses.
Sweep gate	25-volt, positive, ground-clamped, square pulses 37 or 74 μsec in width, depending upon the setting of 6,000- 12,000-yard range selector switch S1604. Leading edge is coincident with time zero and pulse repetition rate is 1 kHz.

control circuit and receiver Doppler circuits, is developed by the Doppler and sweep gate circuits as shown in the illustration. When the local-remote switch is in the local position, timing of the Doppler gate circuit is controlled by the master trigger pulse, which is simultaneously coupled into the Doppler circuit sawtooth generator and the sweep gate multivibrator.

At time zero and with the local-remote switch in the local position, the gate multivibrator produces either a 37-microsecond (6,000-yard) or a 74-microsecond (12,000-yard) sweep gate pulse, determined by the setting of the range selector switch. Simultaneously, the sawtooth generator of the Doppler gate circuit produces a negative sawtooth waveform which is applied to a d -c comparator. However, only a portion of the sawtooth is passed by the comparator since its output is adjustable by a range gate delay control. This means that a measured delay is introduced and the comparator passes only a portion of the sawtooth. As a result the inverter amplifier develops a pulse whose leading edge is in coincidence with time zero and whose trailing edge is adjustable. This gate pulse is now applied to a pulse amplifier where it is differentiated and coupled to the marks mixer along with the range marks. The Doppler gate is also routed to the receiver where it is used to operate the STC and Doppler circuits. These circuits are described later.

TRANSMITTER

The transmitter generates RF pulses which are transmitted to the RF system. It consists of a trigger generator, modulator, magnetron, and associated power supplies. Figure 12-9

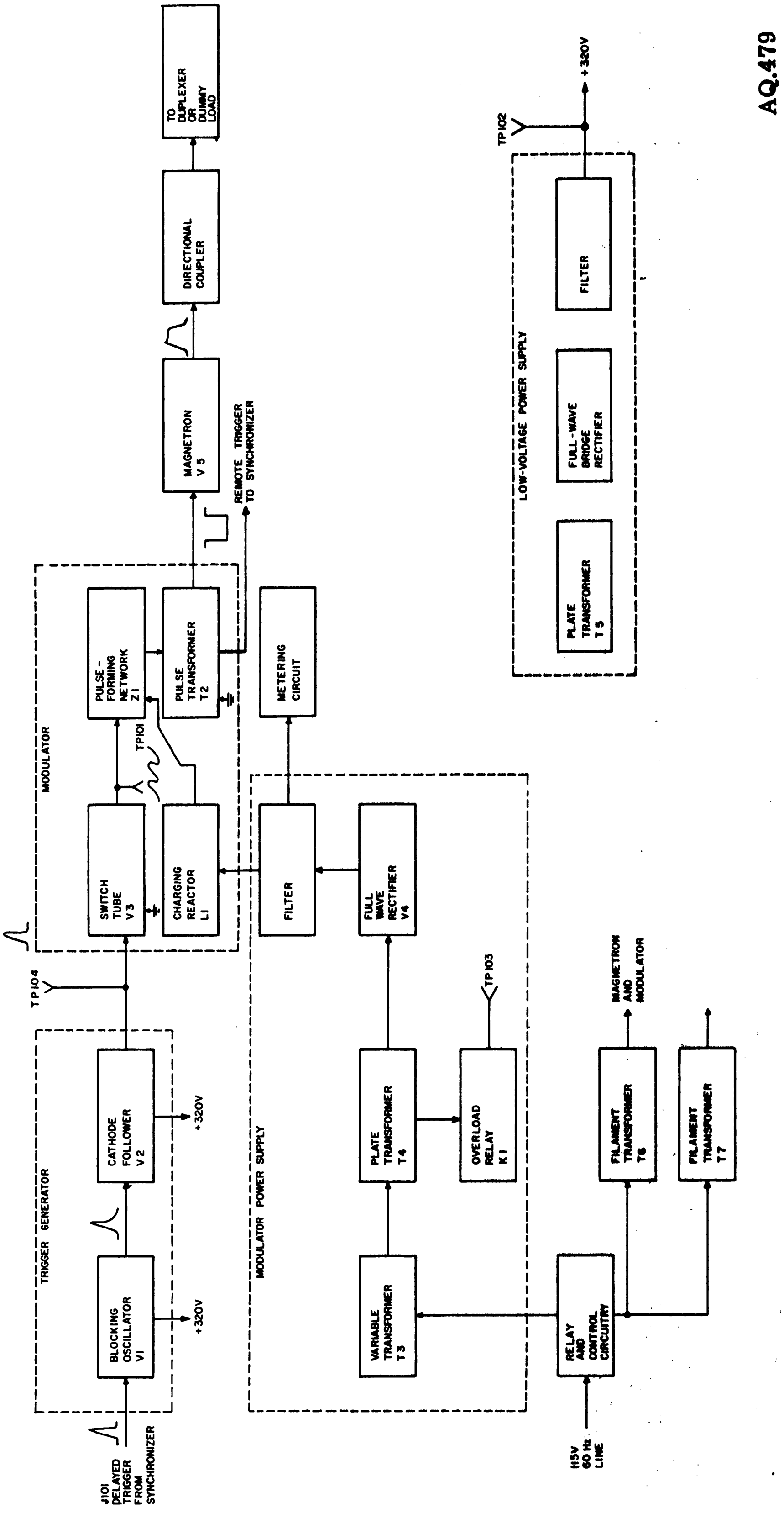

Figure 12-9.—Transmitter block diagram.

illustrates, in block diagram form, the transmitter unit. Inputs to the transmitter are the trigger from the synchronizer, and 115 volts 60 Hz line voltage.

The trigger from the synchronizer is applied to the transmitter trigger generator as illustrated. The trigger generator consists of a blocking oscillator V1 and cathode follower V2, shown in the upper left corner of the illustration. When the transmitter is controlled by the synchronizer, V1 is synchronized to the system PRF by the delayed trigger from the output of the delay trigger circuit. The output of V1 is coupled to the cathode follower V2. The output of the trigger generator is then applied to the modulator switch tube.

As previously mentioned, the 11D13A has special features incorporated to permit operation of each of the major units independently. The transmitter may be operated alone because it has its own power supply and trigger generator. The blocking oscillator, when not synchronized by an external trigger, will free run and has an RC circuit which is adjustable to control the PRF between approximately 700 and 3,000 Hz. Thus, if the free running frequency is adjusted to 900 Hz when the PRF is controlled by the synchronizer, synchronization at 1,000 Hz is accomplished.

The output of the blocking oscillator is a sharp positive going spike, 2 μsec in duration. This pulse is developed across a transformer in the plate circuit of the blocking oscillator and is then used to trigger the switch tube (V3) in the modulator.

The modulator consists of a thyratron used as a switch tube, a pulse forming network Z1 and L1, and the pulse transformer T2. The operation of the modulator is very similar to that described in chapter 11 of this manual, and is not discussed in detail in this chapter.

CAUTION: Voltages necessary to operate a magnetron transmitter-modulator in many radars are in the vicinity of 10,000 volts or more and the technician must observe all safety precautions when working with or near such circuits.

Note in the illustration that the pulse transformer T2 provides the high-voltage pulse to trigger the magnetron and develops a remote trigger which is used in the synchronizer. The RF output pulse from the magnetron is passed to the directional coupler and then into the duplexer or a dummy load. If the RF energy is directed to the duplexer, it may then be sent to the antenna and radiated. If directed to the dummy load, all the energy is absorbed in the load and no radiation takes place.

Referring to the illustration, note that two power supplies are incorporated in the transmitter. These are a high-voltage power supply for the modulator and a low-voltage power supply which provides plate voltages for the trigger generator and two filament transformers which provide filament power to the tubes as indicated.

Included in the power circuits are relay and control circuitry. The purpose is for safety of the technician and also to prevent damage to the components in the high-voltage circuits. To safeguard the technician, a pair of Micro switches removes the input power any time the cover of the transmitter is removed. This type switch is called a safety interlock, since to close the circuit the cover must be in place and this action automatically protects the operator. Never disable these switches—to do so will endanger the life of any person working on the equipment. To prevent damage to the equipment, a 30-second thermal, time delay relay is incorporated to prevent application of power to the high-voltage sections prior to warm up. An overload relay K1 prevents damage to the equipment if a current overload should occur.

RECEIVER

The receiver accepts returned target echoes from the antenna and duplexer system, and transforms them into video signals which are then applied to the indicator display unit. A Doppler signal is also produced in the receiver which is used to provide an audio signal indicating relative target speeds. This Doppler signal is a manufactured signal to indicate closing velocity and is not the same as a pulse Doppler receiver used in actual weapons systems. Recall that the Doppler (range gate) was developed in the synchronizer. Figure 12-10 illustrates the receiver unit in block diagram form and includes an IF-AFC mixer assembly, a sensitivity time control generator (STC), amplifiers for the IF, IAGC, AGC, video and audio, the Doppler circuit, an AFC circuit, and associated power supplies.

Inputs to the receiver are the RF signals from the duplexer, the delayed range gate from the synchronizer, and the 115-volt 60-Hz line voltage supply to the power supply.

Referring to the illustration, note that RF signals are applied to the IF-AFC mixer

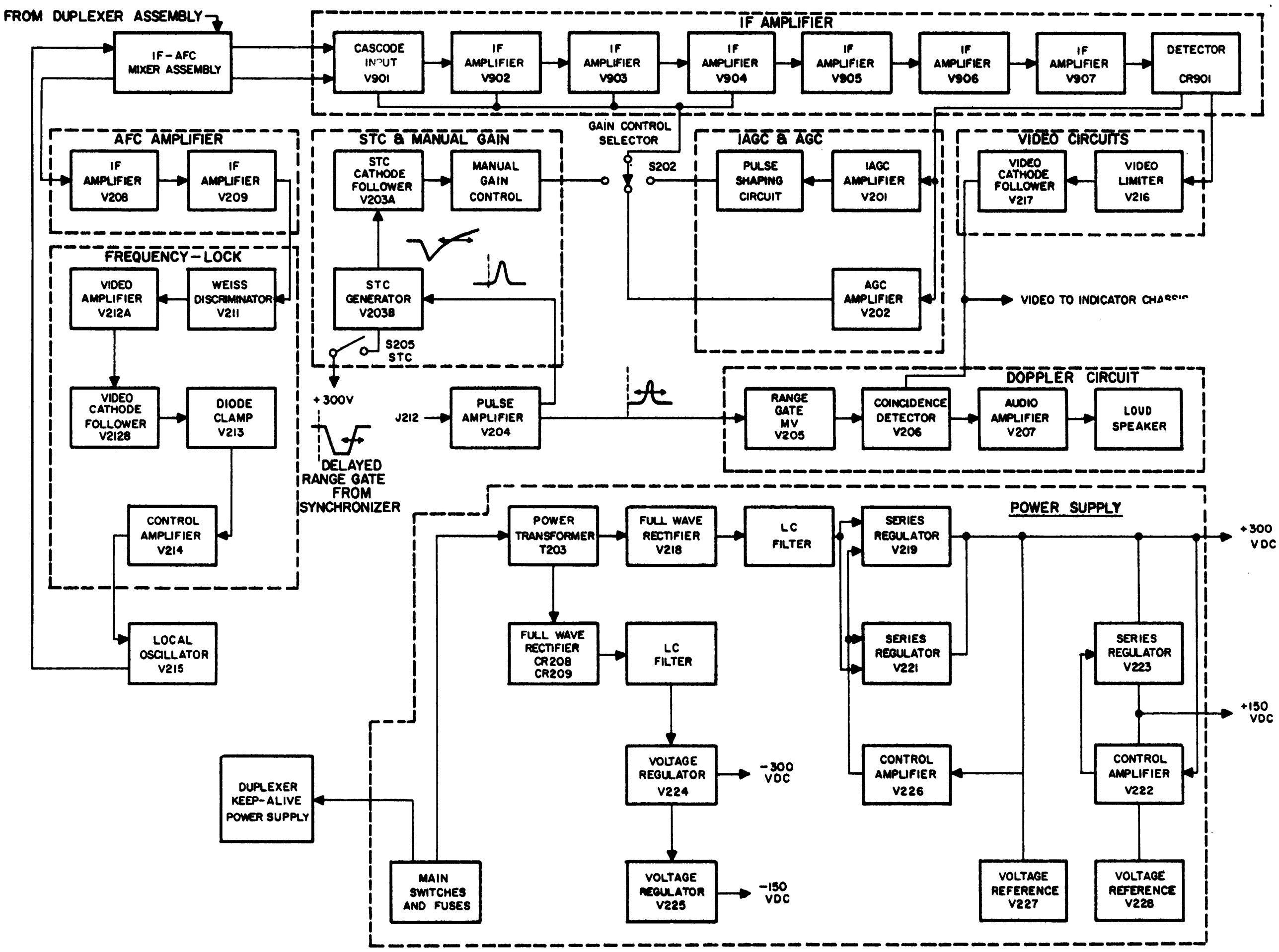

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Figure 12-10.—Receiver block diagram.

assembly in the upper left hand corner of the illustration. In the mixer these signals are combined with the output of the local oscillator (V215). The purpose of the mixer is to produce the difference frequency (IF) signal. Two 30-MHz IF outputs are taken from the mixer assembly; one signal is passed to the IF amplifier, and the second is coupled into the AFC amplifier.

For training purposes, the receiver may also be operated as an independent unit. This is possible since it has its own power supply and an RF signal may be introduced by use of a conventional signal generator.

The 30-MHz signal from the mixer is coupled into the IF amplifier which consists of a cascode input stage, five pentode amplifiers, and a detector. The IF signal is coupled into the amplifier through a double-tuned input transformer. The first two amplifiers, which form the cascode input (V901 and V902), provide a high gain, low noise output. The high signal-to-noise output of V902 is then fed to five identical amplifiers, V903 through V907. These amplifiers are stagger tuned to provide a 4-MHz bandwidth which is required by the receiver. The output of V907 is then coupled into a crystal diode detector where the video is detected.

The output of the detector is a video pulse, negative going, with a duration of 1 microsecond. This 1 microsecond video pulse is fed to one more stage of amplification in the video circuits and from here it is passed on to the indicator unit for presentation on the PPI and/or B-scope indicators. The same video pulse is also coupled into the instantaneous automatic gain control (IAGC) and automatic gain control (AGC) circuits where it functions to control the automatic gain of the receiver.

In figure 12-10 note that a three-position gain control selector switch (S202) is provided to select the type gain control desired. The three positions are IAGC, AGC, and manual gain. When manual gain has been selected, sensitivity time control may also be used. Whether or not this circuit is operational depends on actuation of the on-off STC switch (S205). The purpose of the STC switch is to eliminate the possibility of near targets being obscured. This is accomplished by reducing the gain of the receiver sharply at the instant the transmitter is pulsed, and then allowing the gain to rise to normal over a period of time. This period of time is determined by the setting of the STC control, and the gain rises at an exponential rate. The circuit consists of a pulse amplifier V204, STC generator V203B, and a cathode follower V203A. When the d -c supply voltage is applied by means of the STC on-off switch, the leading edge of the positive range gate from the synchronizer is differentiated, amplified, and clipped in the plate circuit of V204, and used to trigger the STC generator. The leading edge of this pulse is in coincidence with the range gate pulse. Therefore, the leading edge of the exponential waveform produced by the generator will also coincide with the range gate pulse, as illustrated. The exponential rise period, which determines the duration of the STC pulse is controlled by an RC time constant, and is adjustable. The output of the generator is coupled to the cathode follower and then applied to the gain function switch. The initial operating level of this STC circuit is set by the manual gain control.

Doppler Circuit

This system includes a Doppler circuit which is used to detect moving targets. The Doppler circuit consists of a range gate multivibrator V205, a coincidence detector V206, an audio amplifier V207, and a loud speaker. The multivibrator is a monostable flip-flop which is triggered by a pulse from pulse amplifier V204. Since this pulse is initiated by the trailing edge of the synchronizer delayed range gate pulse, (which is variable), the output of the range gate multivibrator V205 is a 2-μsec pulse which may be moved so that its position will coincide with any target within the range of the delayed range gate. The coincidence detector V206 will detect all signals from the video amplifier V217 which occur during the time the gate, generated by V205, is present at the coincidence detector. Any target present in the gate will vary in amplitude if it is moving in range. As the target increases or decreases in range, the video pulses appearing in the range gate will, over a period of time, produce a pulse train which will appear to be amplitude modulated. The modulation frequency will be a function of, and vary directly with, the velocity of the target. The output of V206 is a pulse train which is filtered, passing only the amplitude variations (modulation envelope caused by target movement) to the audio amplifier V207. The output of V207 is then applied to a speaker. An on-off switch is provided for this circuit to allow the operator to silence the Doppler tone if desired.

AFC Circuit

The AFC circuit consists of two amplifiers V208 and V209, a discriminator V211, a video amplifier V212, a clamping diode V213, and a control amplifier V214. The output of this circuit is used to vary the repeller plate voltage of the local oscillator (klystron) so as to maintain the IF (difference frequency) at 30 MHz. This is necessary since the receiver IF circuits are tuned to 30 MHz. The output of the IF-AFC crystal mixer is coupled to the AFC amplifier and amplified by both V208 and V209. The two amplifiers are also tuned to the system's 30-MHz IF.

The output of V209 is then applied to the discriminator V211. V211 is a frequency discriminating circuit which produces output pulses whose amplitude and polarity vary with the frequency shift of the klystron. When the frequency drift of the klystron is in a direction which causes the input to the discriminator to be less than 30-MHz, the output of the discriminator is positive; negative pulses are developed if the discriminator input is greater than 30-MHz. The discriminator is adjusted so that the cross over point (point between plus and minus) of the output is 30.5-MHz. Refer to chapter 11 for complete detailed description of an AFC circuit similar to this one.

INDICATOR

The indicator unit includes both the PPI and B-scope, which are used to display all the information needed by a pilot to make a successful intercept attack on an airborne target, or a bombing attack on a surface target in a bombing mission.

Referring to figure 12-1, note the inputs to the indicator. The range strobe is an input from the range tracking unit; video and switching signals are inputs from the video unit, and necessary power inputs from the power supply.

The B-scope is a CRT with two guns incorporated in a single tube. These are called the A-gun and the B-gun. Each of the guns has an independent deflection system so that in effect the scope is two CRT's sharing a common viewing screen. In the following paragraphs the generation of the different displays produced by each of the guns is discussed.

A-Gun Display Generation

The A-gun is used to display the range circle, breakaway symbol, horizon line, and the steering dot. Since it is impossible to display all of these symbols at the same time, they must be displayed on a time-sharing basis. Each of the symbols is displayed for a controlled period of time which is a function of the time-sharing gates.

The time sharing gates, developed from a 500-hertz reference signal, determine the display sequence. The sequence of the symbols is as follows: range circle or breakaway symbol, horizon line, dot, and clamp.

The range circle is a Lissajous pattern generated by applying two sine waves, phased 90° apart, to the vertical and horizontal deflection plates of the CRT. Figure 12-11 illustrates how a circle is produced in this manner.

As can be seen in the illustration, a circle has been described by passing the electron beam from point-to-point as the two sine waves pass through these points. Note that the voltage waveforms applied to the two horizontal deflection plates are exact opposites, as are the waveforms applied to the vertical plates; but the pulse relationship between the waveforms on the vertical plates and those on the horizontal plates are only 90° out of phase.

Remember, the electron beam is negatively charged, and that like charges repel and unlike charges attract. Starting at point 0 on both the vertical and horizontal plates, the left horizontal plate is at maximum positive and the right horizontal plate is at maximum negative. The effect of these two voltages is that the positive voltage attracts the electron beam, while the negative voltage repels the beam. This action will cause the beam to be displaced to the left on the screen, and the electrons in the beam striking the face of the tube will cause a bright spot.

If these voltages were to remain in this position, the spot would not move. However, as the sine waves continue in time (0 to 1), it can be seen that the voltage on each horizontal deflection plate moves toward zero; the voltage on the vertical deflection plates moves toward maximum—the top waveform going in the positive direction and the bottom waveform going in the negative direction. As time proceeds, the waveforms on the horizontal plates produce less and less influence on the beam while those on the vertical plates produce an influence which is increasing. This causes the beam to be moved smoothly from point 0 to point 1 causing an arc to be written on the phosphor-coated screen of the CRT.

As the electron beam strikes the face of the tube, the phospher is caused to glow, leaving a trail of light behind it. This action continues on through points 2 and 3 and back to point 0, writing a complete circle on the CRT screen. If the frequency of these waveforms is very low, the electron beam would move around the circular path very slowly, and the trail or light would fade, as indicated in the illustration. Normally the frequency of the applied voltages is high, causing the beam to sweep over the face of the tube very fast, and one complete circle is written before the beginning of the circle can fade. Also, the circle is gated ON more than one time, and it appears to be continuous.

As previously mentioned, the A-gun is used to present not only the range circle, but also the horizon line, the breakaway X, and the steering dot. Each of these symbols are written on the face of the CRT one at a time, in a special sequence, and each is written over and over so as to present the particular symbol as continuous. This means that each symbol must share a portion of the entire time required to present them all. At this point refer to figure 12-12, which illustrates, in block diagram form, how this timing is accomplished.

Note in the upper left corner of figure 12-12 the block labeled 500-Hz oscillator. This oscillator has two outputs—one is a 500 Hz reference

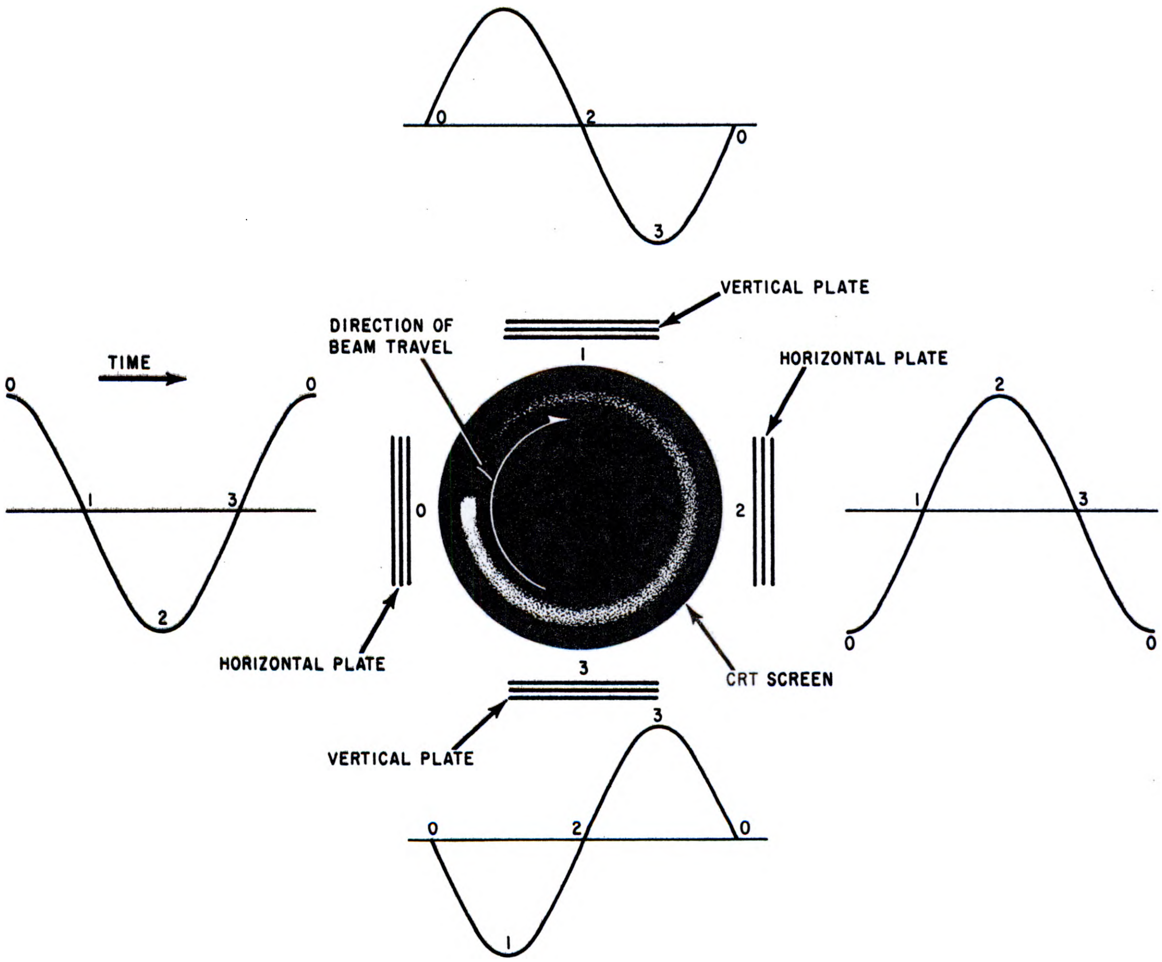

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Figure 12-11.—Generation of a circle on a CRT.

signal, and the other is a 500 Hz synchronizing signal. The sync signal is applied to the gate multivibrator, A1502. The reference signal is applied to the amplifier gate generator A1503, pin 5 of J1522, range circle generator A1506, and breakaway generator A1505.

The range circle generator output is two sine waves which are 90° out of phase. The signal from pin 7 has been shifted by -45° and the signal from pin 12 has been shifted by +45°. The ±45° shift is in respect to the input 500-Hz reference signal. Note also that range voltage is an input to the circle generator; this voltage determines the size of the range circle on the indicator. The two potentiometers R1515 and R1516 are used to balance the d -c level in the output. The two output signals are then applied to relay K1501 and are used as inputs to the vertical and horizontal circle gates.

When the range circle is to be presented on the indicator, the sine waves must be gated through the vertical and horizontal gates. The gates used for this purpose are generated in the gate multivibrator, A1502. The circle gate is an 8-millisecond negative square wave from the gate multivibrator (pin 18), which is applied to the vertical and horizontal gates. The outputs of these two units are the vertical and horizontal deflection voltages for the range circle. The two deflection voltages are applied to the A-gun

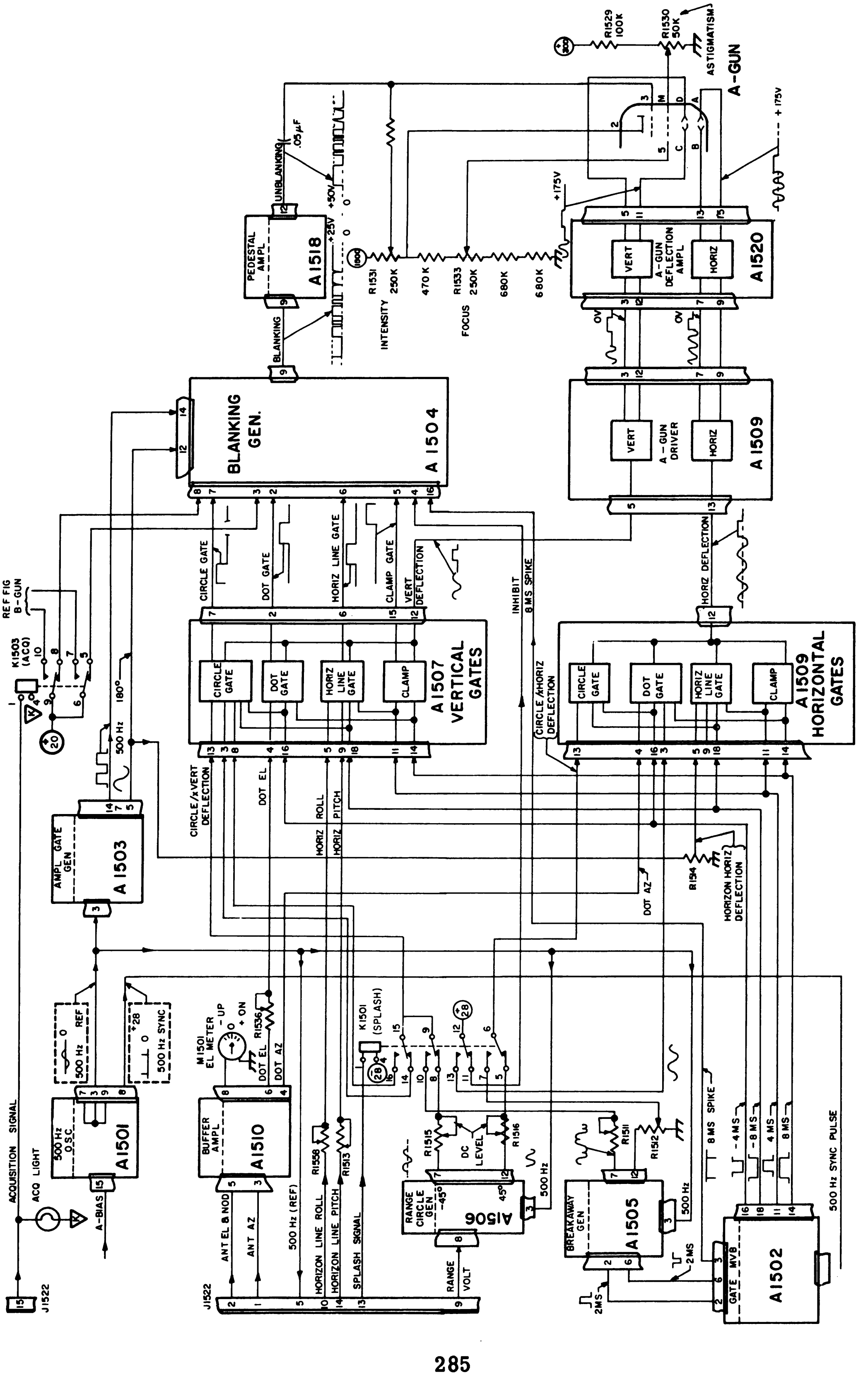

Figure 12-12.—B-scope, A-gun block diagram.

driver and deflection amplifier circuits, and are then placed on the vertical and horizontal deflection plates of the A-gun. Although the deflection voltages are applied to the deflection plates of the CRT, the circle would not appear unless the tube is conducting. In order for this to occur, an unblanking pulse must be applied at the same time. Note in the upper right hand corner of figure 12-12, a positive 50-volt pulse train unblanking waveform. The portion indicated by the arrow is the unblanking pulse for the range circle. The circle is written twice each time the circle unblanking gate appears. The complete cycle time required to present all of the symbols is shown as 16 milliseconds (fig. 12-13). Line 1 shows the 500-Hz reference signal, and below this are the gates and waveforms for each of the symbols illustrated in their proper time relation.

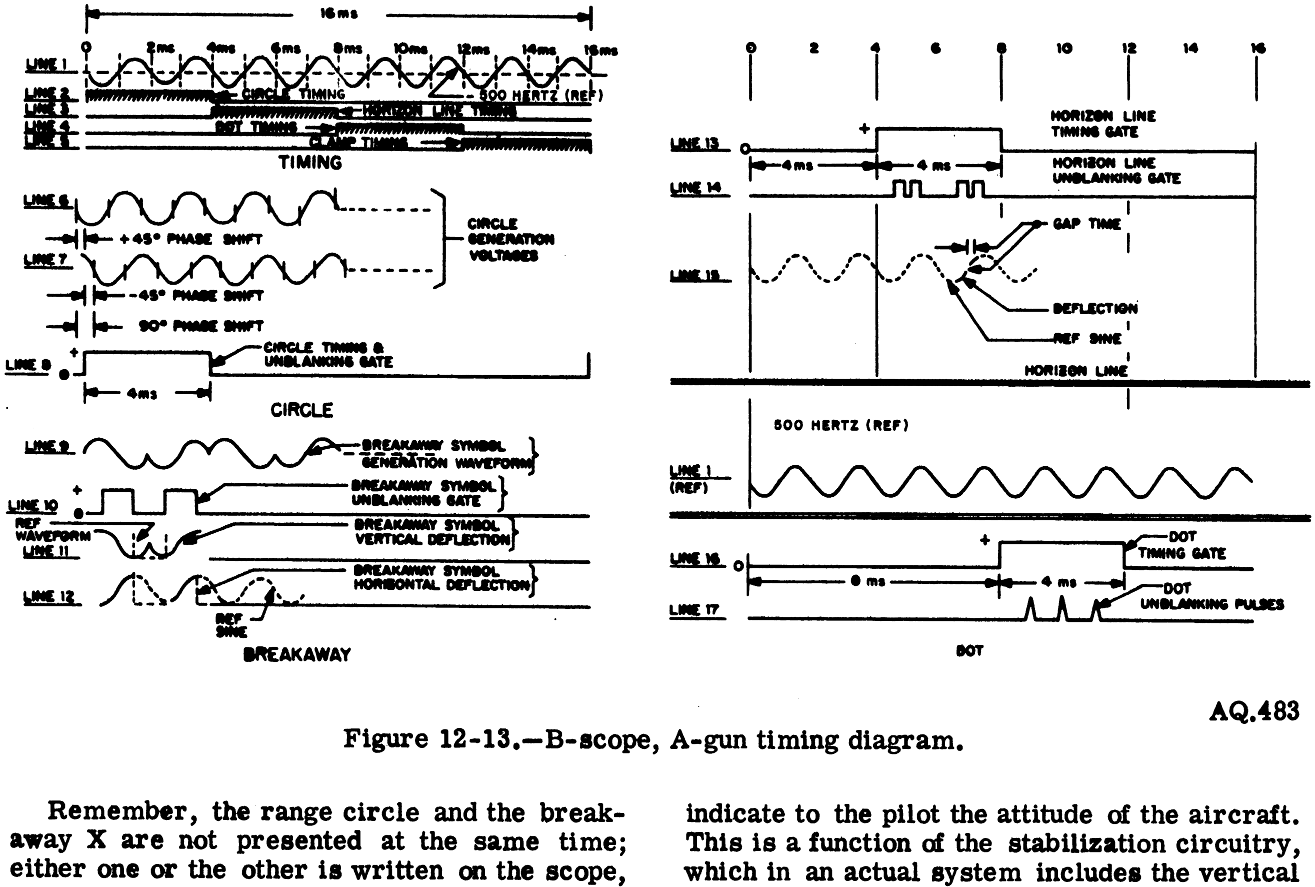

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Figure 12-13.—B-scope, A-gun timing diagram.

Remember, the range circle and the breakaway X are not presented at the same time; either one or the other is written on the scope, using the same time period. To switch from the range circle to the breakaway X, relay K1501 (fig. 12-12) is energized by the signal shown as the splash signal. The splash signal is an input at pin 13 of J1522.

In the timing diagram, lines 2 through 5 show the timing gates, including a gate called clamp timing. The purpose of the clamp is to maintain the bias level on the tube to control the intensity of the symbols as they are gated on at the beginning of each cycle; intensity is initially set by R1531. Note that the bias for the CRT is provided by the voltage divider network between ground and the negative 1500 volts. Focus is controlled by focus control R1533 and astigmatism control R1530.

Recall that the position of the dot is an indication of the antenna position, and is therefore a part of the horizontal and vertical deflection signal. The voltages used to position the dot are outputs of the buffer amplifier A1510 (pins 6 and 4). Also, recall that the horizon line will indicate to the pilot the attitude of the aircraft. This is a function of the stabilization circuitry, which in an actual system includes the vertical gyro. These inputs are shown as horizon roll and pitch signals, applied to the vertical horizon line gate. These inputs become part of the vertical deflection voltages applied to the CRT and cause the horizon to follow the outputs of the stabilization circuits orienting the position of the horizon with that of the aircraft.

Two items shown in figure 12-12 are the acquisition light in the upper left hand corner, and a meter used to indicate the position of the antenna shown just to the right of the buffer amplifier. To illuminate the acquisition light, an acquisition signal is applied to the acquisition relay K1503 via pin 15 of J1522. This light remains illuminated as long as the radar is locked on the target and is tracking.

B-gun Display Generation

The B-gun is used to display the range sweep line, acquisition symbol, and target video. The range sweep line and acquisition symbol are displayed on a time-shared basis. The video is the result of intensity modulation of the electron beam as it sweeps in range. The sequence of the display is the range sweep line followed by the acquistion symbol. In the following paragraphs refer to figure 12-14 which is a block diagram of the B-gun, and to figure 12-15, the B-gun timing diagram.

The signals required to generate and display the range sweep line are as follows: A sawtooth of voltage applied to the vertical deflection plates, an azimuth position voltage applied to the horizontal deflection plates, and an unblanking gate applied to the cathode of the CRT.

In figure 12-14, in the upper left corner, a trigger from the system (or an internal trigger) is applied to the range sweep generator through S1501 and K1502. If K1502 is energized, a delay trigger is used to start the B-scope range sweep generator. The outputs of the range sweep generator A1511 are a range sweep sawtooth and a range gate, which start at the time the trigger is applied. See figure 12-15, lines 1, 2, and 3. Duration of the range sweep gate and the slope of the sweep sawtooth are determined by the range switch S1502. These different ranges are shown superimposed in lines 2 and 3 of figure 12-15. In addition, the range sweep generator provides unblanking and time for the PPI scope. When K1502 is energized, the trigger applied to the range sweep generator comes from the delayed sweep generator A1512.

Inputs to the delayed sweep generator are the system trigger (or internal trigger) and range voltage, which is a d-c control voltage signal. The output is a trigger which has a delay with respect to the input, and is controlled by the input d-c control signal. This output is shown in figure 12-15 line 4. The resultant range sweep voltage is then applied to the B-gun deflection amplifier A1519 and then to the B-gun vertical deflection plates. (See fig. 12-14.) Unblanking for the range sweep display is obtained by applying the range sweep gate, through the pedestal amplifier A1518, to the B-gun cathode. The horizontal position of the B-sweep is controlled by an input signal applied through K1502 (pins 5 to 6 or 7 to 6), to the horizontal switch A1517, to B-gun deflection amplifier A1519, then to the B-gun horizontal deflection plates. This positioning signal originates in the antenna sweep circuits and is applied to the buffer amplifier A1510. The output of the buffer amplifier is at pin 9 during normal sweep and is at pin 12 during expanded sweep.

Time sharing for the acquisition display is initiated by the range gate, which is applied to the acquisition symbol generator at pin 2 of A1514. The trailing edge of the range gate is used to start the generator. Other inputs required for the display include a 20-kHz sine wave from the 20-kHz oscillator A1515 (pin 9) which is applied to pin 9 of the acquisition symbol generator and used to determine the length of the symbol, and a 20-kHz square wave intensity signal from oscillator A1515. The intensity signals are shown as an output from pin 7 of the oscillator and as an input to the 10-kHz multivibrator pin 7. The output of this multivibrator is a 20-kHz intensity pulse which is taken from pin 5 and applied to the acquisition symbol generator pin 5. These pulses are gated through the symbol generator and are an output at pin 7. From here they are applied to the grid, (pin 7) of the video mixer V1504. From the video mixer, the pulses are sent to the video amplifier V1505 and applied to the grid (pin 10) of the CRT. These same intensity pulses are also applied to the pedestal amplifier and 1-kHz multivibrator A1518 as the acquisition symbol unblanking signal. This input is at pin 3 of A1518 and is the B-gun unblanking pulse (pin 5). From here it is applied to the cathode of the CRT to unblank the tube during the time the vertical and horizontal signals for the acquisition symbol are present on the deflection plates of the CRT.

Inputs and outputs of the acquisition symbol generator are shown in their time relation in figure 12-15. Line 10 of the figure shows the portion of the 20-kHz sine wave which is actually

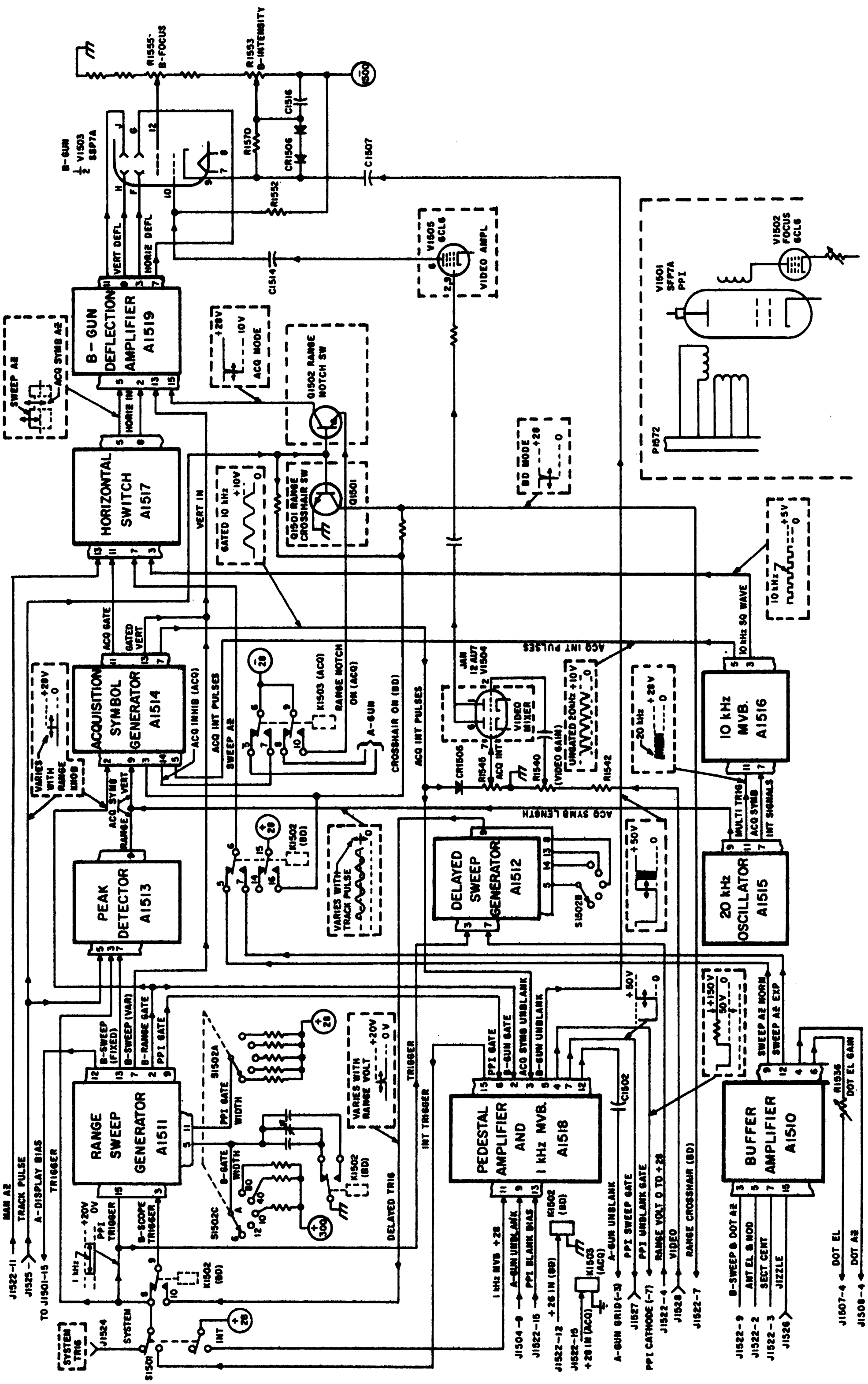

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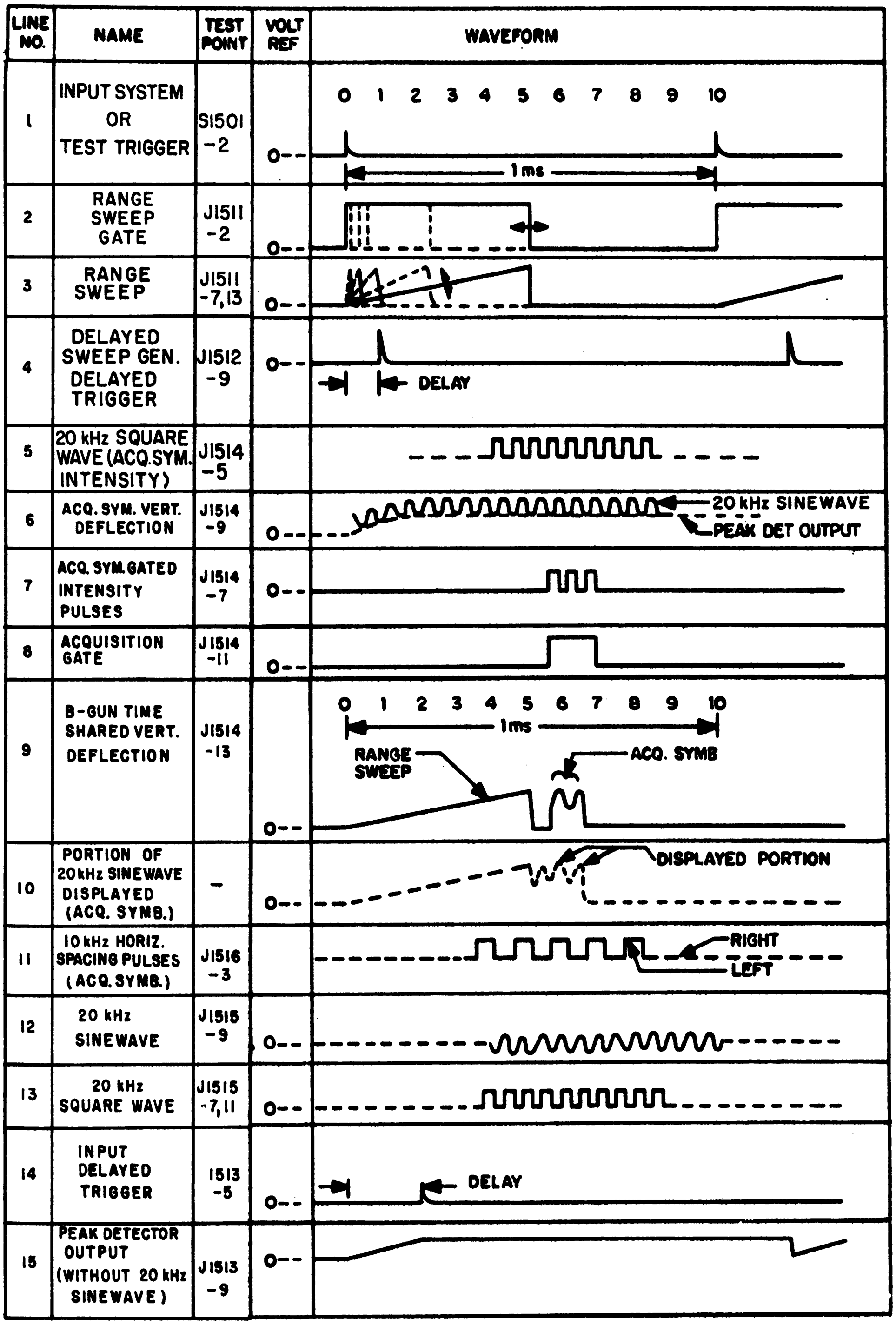
Figure 12-14.—B-gun display generation block diagram.



LINE NO.	NAME	TEST POINT	VOLT REF
1	INPUT SYSTEM OR TEST TRIGGER	S1501 -2	0--
2	RANGE SWEEP GATE	J1511 -2	0--
3	RANGE SWEEP	J1511 -7,13	0--
4	DELAYED SWEEP GEN. DELAYED TRIGGER	J1512 -9	0--
5	20 kHz SQUARE WAVE (ACQ.SYM. INTENSITY)	J1514 -5	
6	ACQ. SYM. VERT. DEFLECTION	J1514 -9	0--
7	ACQ. SYM. GATED INTENSITY PULSES	J1514 -7	0--
8	ACQUISITION GATE	J1514 -11	0--
9	B-GUN TIME SHARED VERT. DEFLECTION	J1514 -13	0--
10	PORTION OF 20kHz SINEWAVE DISPLAYED (ACQ. SYMB.)	-	0--
11	10 kHz HORIZ. SPACING PULSES (ACQ. SYMB.)	J1516 -3	
12	20 kHz SINEWAVE	J1515 -9	0--
13	20 kHz SQUARE WAVE	J1515 -7,11	0--
14	INPUT DELAYED TRIGGER	1513 -5	0--
15	PEAK DETECTOR OUTPUT (WITHOUT 20 kHz SINEWAVE)	J1513 -9	0--

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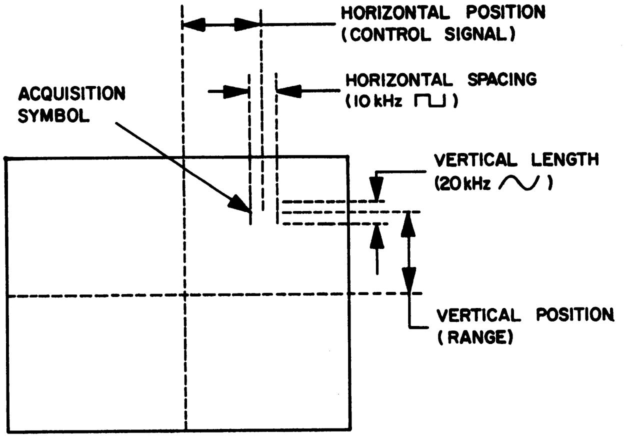
Figure 12-15.—B-gun timing diagram.

displayed as the two vertical lines that make up the acquisition symbol. Line 11 shows the waveform which is used to space the lines in the horizontal. Figure 12-16 illustrates how these


HORIZONTAL POSITION (CONTROL SIGNAL)
HORIZONTAL SPACING (10 kHz ⊓⊔)
ACQUISITION SYMBOL
VERTICAL LENGTH (20 kHz ∿)
VERTICAL POSITION (RANGE)

AQ.486
Figure 12-16.—Acquisition symbol generation.

signals are applied in respect to the symbol which is generated.

INDICATOR VIDEO UNIT

The indicator video unit is the system's interconnection and control center. It contains the computational antenna (antenna position servo which generates the signals that the actual antenna follows) and scan pattern generator. It also generates the PPI sweep and deflection signals, and processes and amplifies all video signals for both of the indicator displays. Most signals of the system are interconnected through the video unit as illustrated in figure 12-1.

Mode Switching

Control of the system is initially dependent upon the scan control switch, S1405. (See fig. 12-17.) This switch has two positions (PPI and SECTOR). When the switch is in PPI, the antenna is caused to scan 360°; the rpm of the scan may be automatic at 6 rpm or it may be manually controlled by S1404, as previously described. PPI position is selected for normal radar search. With the scan switch in the SECTOR position, either fire control (FC) or bomb director (BD) operation may be selected. To select either FC or BD, a separate switch, S1406 (FC-BD switch) is provided. In the FC position a 6° nod is introduced by the nod cam S1402 through the closed contacts of K1403. For the BD mode of operation, an azimuth mark signal is produced by the azimuth mark cam S1403 and sector center is controllable through use of sector center control R1443. Other controls are the azimuth, elevation, and range controls. These controls operate to transfer antenna control to manual, and also allow for positioning of the acquisition symbol and range and azimuth strobes.

Selection of the bomb director mode disables the action switch of the azimuth and range potentiometers, and the nod signal. At the same time, the azimuth mark signal is fed into the video circuits. The PPI sweep is doubled and the center is depressed one radius; the expanded sweep circuits for the indicators are energized, and sector center control is removed, at which time azimuth mark control is substituted.

Selection of the fire control mode allows relays K1401, K1402, and K1403 to be operational, which control the sequencing in the FC mode. During FC search operation, these relays are deenergized and the radar operates with a 60° sector scan, with a steerable sector center and a 6° nod. The acquisition symbol is presented along with the B-scan, and is controllable in both range and azimuth, and the antenna is controllable in elevation. When the action switch is depressed, K1401 and K1403 are energized, transferring the azimuth control of the antenna and the display to manual operation and, at the same time, disables the nod circuit. By movement of the range, azimuth, and elevation controls the target is brought into coincidence with the range track gate. When this occurs, the acquisition mode is actuated energizing K1402 and K1403. This operation is now manual track and the position of the track gate is controlled from the three previously mentioned position controls. The acquisition symbol is replaced by a range notch and the PPI scope is disabled.

Upon release of the action switches, K1401 is deenergized which permits the tracking error signals to control the position of the antenna, maintaining automatic tracking of the target. If loss of the target occurs, the tracking signal from the track chassis disappears, and the system is placed in automatic search by deenergized relays K1402 and 1403.

Scan Pattern Generator and Antenna Position Servo

In the center of figure 12-17 is illustrated the scan pattern generator. The sector-scan patterns of BD and FC are generated by a

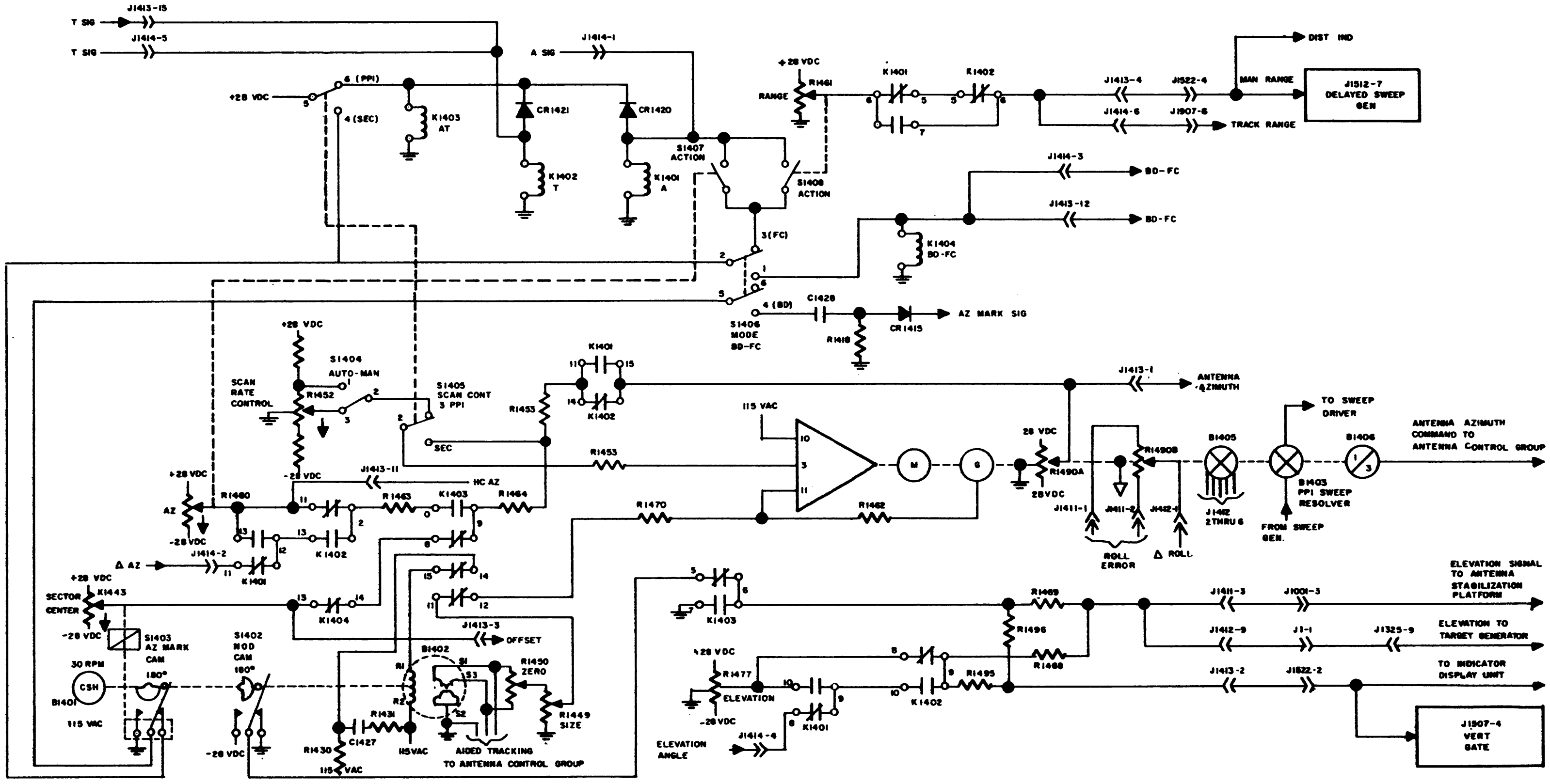


Figure 12-17.—Indicator video unit simplified schematic.

60-Hz resolver driven by a 30-rpm constant speed motor. The sine wave output of the resolver is used as the basic scan pattern signal and it is to this signal position that the nod and azimuth mark cams are alined. The azimuth mark cam is set to just before the 180° point of the pattern and the nod cam is set to just before the 90° position of the pattern.

There are actually two antennas in the system; one is the actual RF transmitting antenna which is mounted on the antenna stabilization platform. The other is called a computational antenna which the true RF antenna follows. The computational antenna is a conventional position-following servo as described in chapter 6 of this manual. The scan-pattern signal is fed into a servoamplifier where it is compared with a chopped and amplified d-c input from the antenna position potentiometer R1490. The error signal drives the antenna position servo to follow the scan pattern generator. On the same shaft as the position potentiometer R1490 are the PPI sweep resolver, RF antenna synchro, and the antenna position resolver for the target generator.

Video Amplifier Section

The video amplifier section is simply a mixer stage for the range marks, azimuth mark and video, and the range crosshair. Referring to figure 12-18, note that the tube V1412(A and B) is the mixer and that the tube V1413 is the amplifier. Range marks from the synchronizer are injected at grid 7 of the mixer (V1412). (This is only when the 6,000- and 12,000-yard ranges are selected.) The size of the marks is controlled by R1410B, the range marks amplitude potentiometer. The azimuth mark, during bomb director operation, and the receiver video are injected at grid 2 of V1412B. Receiver video is controlled by the video amplitude potentiometer R14111.

The range crosshair is applied to the mixer tube at the cathode of section B. Since this tube is a dual triode with its plates tied together, all of the signals are mixed at the plates. The amplifier V1413 then amplifies the entire signal. The output, which is at a 60-volt level, is then passed to the indicator display unit for use on the PPI and for further signal addition for B-scope video signals.

Azimuth Marks Generator

The azimuth marks generator (fig. 12-19) produces an azimuth mark on the PPI scope that marks the center of the sector-scan when operating in bomb director mode. Also, the output of this generator produces the vertical portion of the crosshairs on the B-scope. Two input signals are applied to the generator; one is taken from the servo potentiometer R1490A, which is a voltage that sweeps above and below zero and represents the sector-scanning of the antenna.

The second input is a d-c voltage taken from the servo potentiometer R1443, which represents the center of the sector being scanned by the antenna.

Both voltages are summed in a summing network formed by fixed resistors R19, R3, R2, and R4, and potentiometers R1 and R5. Potentiometer R1 adjusts the amplitude of the sector-center input voltage and R5 adds an offset voltage to the sum of the input of AR1 to adjust the azimuth marks on the scope. A full wave limiter, Zener diodes CR7 and CR8, limits the input to AR1 to prevent overdriving the amplifier. As the antenna scans from right to left, the input from azimuth potentiometer R1490A becomes progressively less positive. As the sum of the inputs are fed to AR1, its output remains at some positive level. As the antenna reaches sector-center, the sum of the sector-center voltage from R1443 and azimuth voltage from R1490A equates zero or slightly negative; this causes the output of AR1 to be negative. The output will remain negative until the antenna reaches sector-center on its left to right scan, at this time it will again swing positive. Resistor R7 and inductor L1 form an RL differentiator and shapes the output of AR1 into a sharp negative pulse which is used to trigger sector-center gate generator A1.

Sector-center gate generator A1 is a single shot (monostable) multivibrator responding only to negative input triggers. Since a negative input trigger is only generated when the antenna scans from right to left, A1 generates a scan gate only when the antenna scans from left to right. External RC components connected to A1 cause the circuit to generate a 4,000-microsecond negative gate when it is triggered. This negative 4,000-microsecond gate is applied as one input of a two input AND gate consisting of diodes CR1, CR2, and resistor R9. A 500-microsecond negative range gate input is passed through emitter follower Q3 which scales down the amplitude to a value required by the mark generator. Diode CR2, the second input of the AND gate, receives the negative range gate.

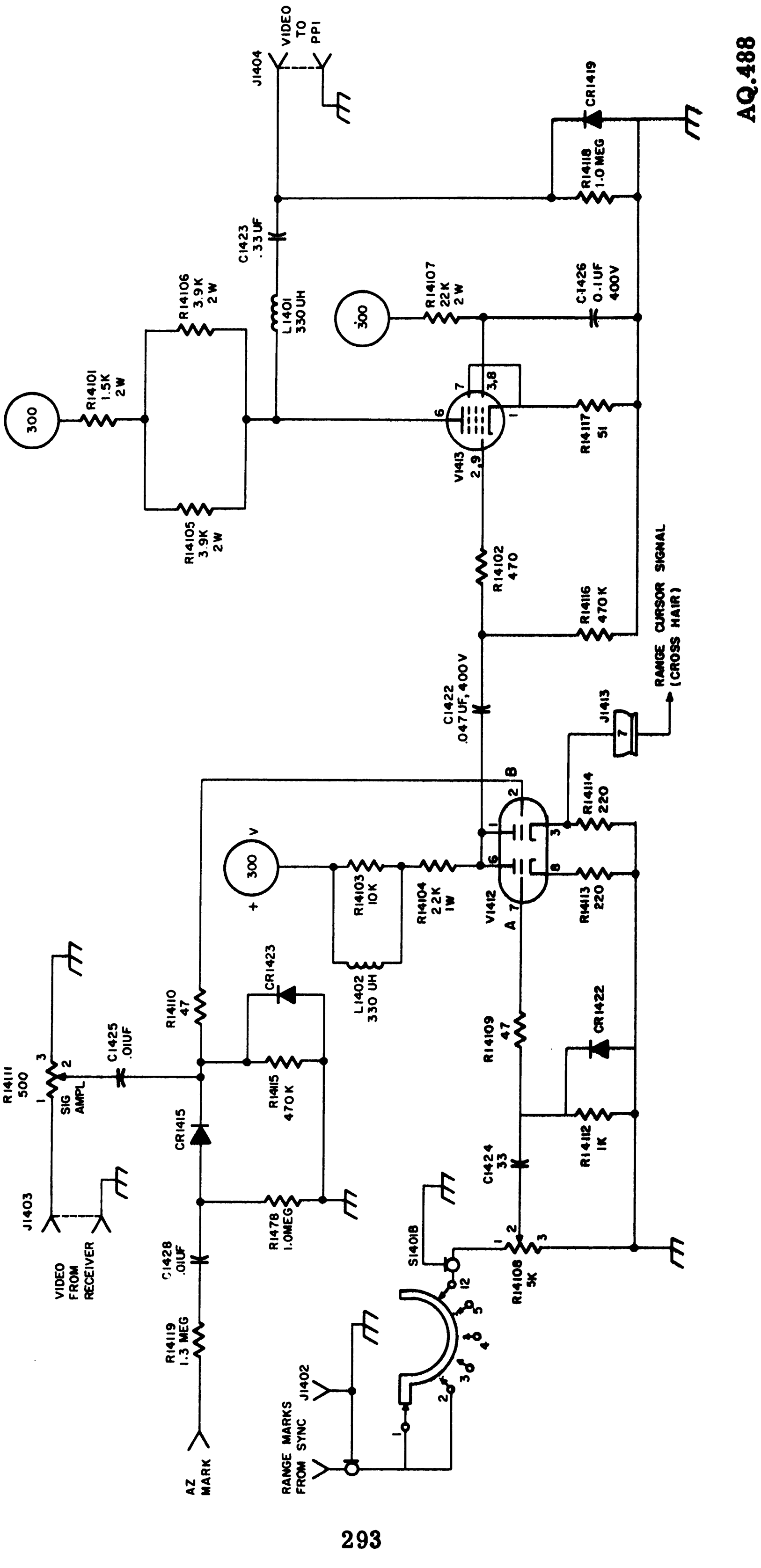


Figure 12-18.—Video amplifier section.

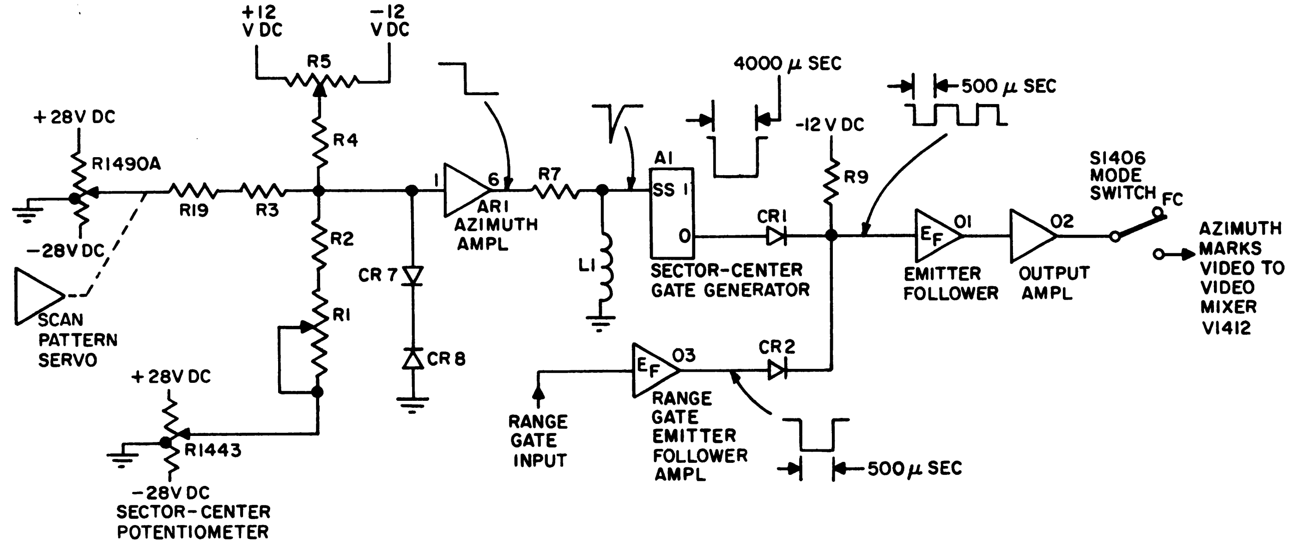


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Figure 12-19.—Azimuth marks generator.

When the anodes of AND gate diodes CR1 and CR2 are both negative, the input to Q1 is also negative. Since the sector-center gate is eight times as wide as the range gate, as many as four range gates pulses could be passed through the AND gate. The output pulses of the AND gate are the azimuth mark video pulses which produce the azimuth mark on the center of the PPI sector scan and the B-scope. Emitter follower amplifier Q1 couples the output of the AND gate to output amplifier Q2, which feeds the mark video pulses through MODE switch S1406 in the bomb director position to video mixer tube V1412.

RANGE TRACKING UNIT

The range tracking unit allows the radar to track a target in range; and, if the input target video is applied from the target generator it also develops antenna azimuth and elevation signals. These error voltages, applied to the antenna position servo and stabilization platform systems, allow the radar to track the target in angle (azimuth and elevation) as well as in range. The tracking unit tracks the target in range by generation of a range strobe (gate) and positioning the strobe in time (range) so that it coincides with the range of the target. After radar lockon, range tracking is accomplished by automatically and continuously adjusting the time of the range strobe, as the target changes range.

Angle tracking error signals are derived from the amplitude modulation on the target video pulses. The amplitude modulation is detected, and the phase of the detected signal is compared in a phase sensitive circuit with a reference signal. A d-c error voltage is developed according to the phase difference, and is used to represent the antenna tracking error; this voltage is then applied to the antenna position servo in the indicator unit and to the antenna servosystem. Figure 12-20 illustrates, in block diagram form, the range tracking unit.

Range strobe pulses, which are 2 μsec in duration, are generated at the system trigger rate. The input for the system trigger is at J1905 on the illustration. This trigger is first inverted across Q1921, and then applied to a sweep gate which operates a bootstrap sweep generator. Recall that the output of a bootstrap sweep generator is a sawtooth wave of voltage which is very linear. The starting point of the sweep sawtooth is in coincidence with the system trigger, and the width of the sweep is dependent upon whether the system is operating in FC or BD mode. This sawtooth is then applied to CR1926, which is a range-comparator diode.

Since CR1926 is a comparator, it must have something with which to compare the sweep sawtooth. The voltage to be compared is the

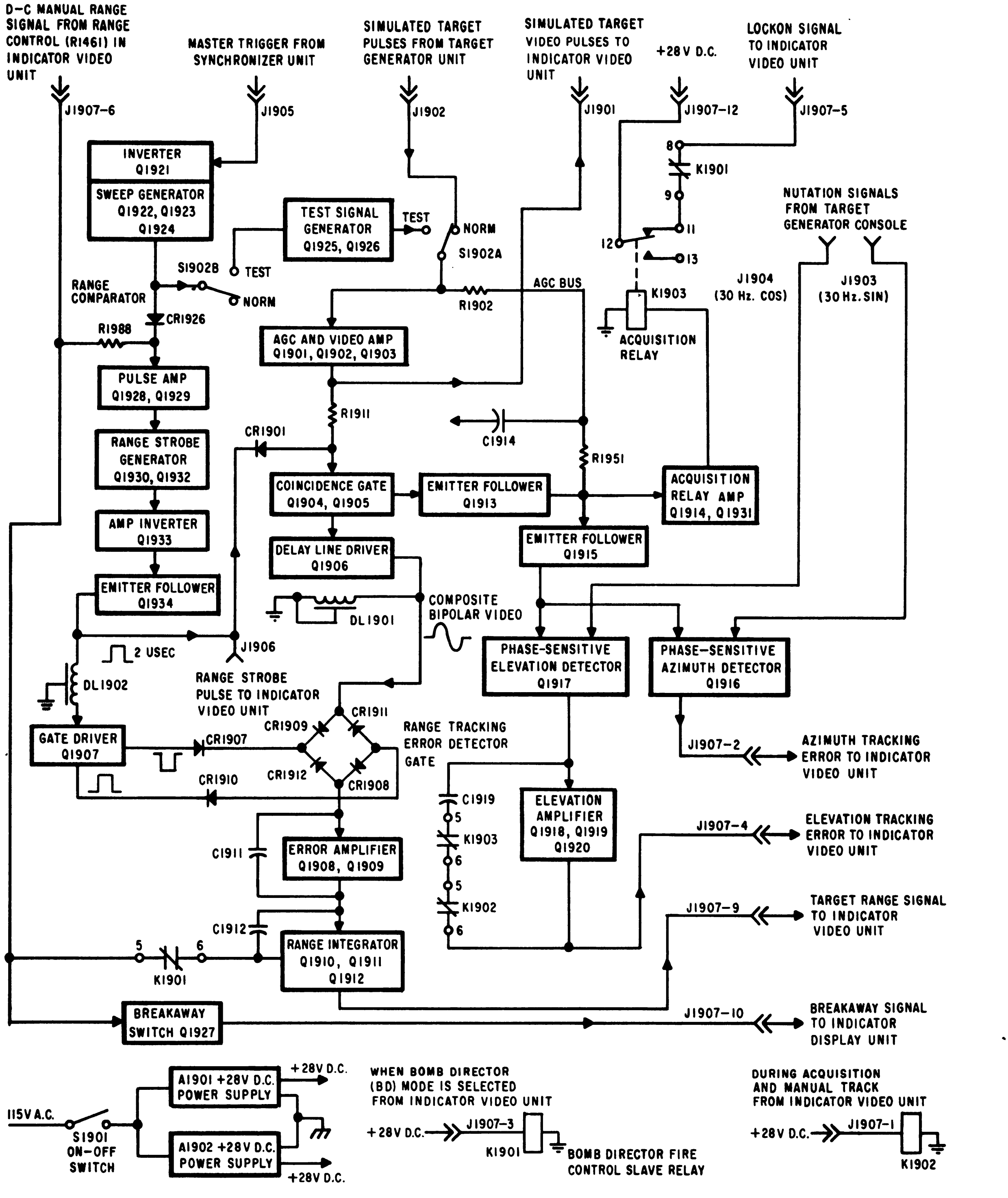
D-C MANUAL RANGE SIGNAL FROM RANGE CONTROL (R1461) IN INDICATOR VIDEO UNIT
J1907-6
MASTER TRIGGER FROM SYNCHRONIZER UNIT
J1905
SIMULATED TARGET PULSES FROM TARGET GENERATOR UNIT
J1902
SIMULATED TARGET VIDEO PULSES TO INDICATOR VIDEO UNIT
J1901
+28V D.C.
J1907-12
LOCKON SIGNAL TO INDICATOR VIDEO UNIT
J1907-5
INVERTER Q1921
SWEEP GENERATOR Q1922, Q1923 Q1924
TEST SIGNAL GENERATOR Q1925, Q1926
TEST
NORM
S1902A
S1902B
TEST
NORM
RANGE COMPARATOR
CR1926
R1988
R1902
AGC BUS
8
K1901
9
11
12
13
K1903
ACQUISITION RELAY
NUTATION SIGNALS FROM TARGET GENERATOR CONSOLE
J1904 (30 Hz. COS)
J1903 (30 Hz. SIN)
AGC AND VIDEO AMP Q1901, Q1902, Q1903
PULSE AMP Q1928, Q1929
R1911
C1914
R1951
CR1901
RANGE STROBE GENERATOR Q1930, Q1932
COINCIDENCE GATE Q1904, Q1905
EMITTER FOLLOWER Q1913
ACQUISITION RELAY AMP Q1914, Q1931
AMP INVERTER Q1933
DELAY LINE DRIVER Q1906
EMITTER FOLLOWER Q1915
EMITTER FOLLOWER Q1934
DL1901
COMPOSITE BIPOLAR VIDEO
2 USEC
J1906
DL1902
RANGE STROBE PULSE TO INDICATOR VIDEO UNIT
PHASE-SENSITIVE ELEVATION DETECTOR Q1917
PHASE-SENSITIVE AZIMUTH DETECTOR Q1916
CR1911
CR1909
RANGE TRACKING ERROR DETECTOR GATE
GATE DRIVER Q1907
CR1907
CR1912
CR1910
CR1908
J1907-2
AZIMUTH TRACKING ERROR TO INDICATOR VIDEO UNIT
C1919
5
K1903
6
5
K1902
6
ELEVATION AMPLIFIER Q1918, Q1919 Q1920
C1911
ERROR AMPLIFIER Q1908, Q1909
J1907-4
ELEVATION TRACKING ERROR TO INDICATOR VIDEO UNIT
J1907-9
TARGET RANGE SIGNAL TO INDICATOR VIDEO UNIT
C1912
5
6
K1901
RANGE INTEGRATOR Q1910, Q1911 Q1912
BREAKAWAY SWITCH Q1927
J1907-10
BREAKAWAY SIGNAL TO INDICATOR DISPLAY UNIT
A1901 +28V D.C. POWER SUPPLY
+28V D.C.
115V A.C.
S1901 ON-OFF SWITCH
A1902 +28V D.C. POWER SUPPLY
+28V D.C.
WHEN BOMB DIRECTOR (BD) MODE IS SELECTED FROM INDICATOR VIDEO UNIT
+28V D.C.
J1907-3
K1901
BOMB DIRECTOR FIRE CONTROL SLAVE RELAY
DURING ACQUISITION AND MANUAL TRACK FROM INDICATOR VIDEO UNIT
+28V D.C.
J1907-1
K1902

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Figure 12-20.—Range tracking unit block diagram.

range voltage shown in the illustration as d-c manual range signal. This manual input comes from the range potentiometer R1461 in the indicator video unit, and is applied to R1988 through J1907, and then to the comparator CR1926. An output is developed across R1988 when the amplitude of the sweep sawtooth exceeds the d-c range voltage. Thus, the comparator output is delayed in time by an amount corresponding to range strobe position (range).

The output of the comparator is then amplified to sharpen the leading edge, and is used to trigger the range strobe generator. The range strobe generator is a monostable multivibrator which generates a 2-μsec pulse each time it is triggered. The 2-μsec pulse is then amplified, inverted, and taken from Q1934, an emitter follower, as a 2-μsec positive range strobe pulse. The range strobe is next applied to delay line DL1902, and then to gate driver Q1907. Note also that the range gate is applied to J1906 (and sent to the indicator video unit) and to the coincidence gate through CR1901.

The target that is to be tracked is an input at J1902 through switch S1902A and into the AGC and video amplifier. The amplified video pulses are an output to the indicator, through J1901, and are also an input across R1911 into the coincidence gate. If the range strobe pulse is in coincidence in time with the target video pulse, the coincidence gate will accept the video pulses. The coincidence gate provides a negative output to emitter follower Q1913, and a positive output to delay line driver Q1906.

The output of the emitter follower is filtered across R1951 and C1914 and used as AGC voltage for the video amplifier. The AGC voltage also operates the acquisition relay amplifiers, which deenergize K1903 when the AGC voltage is sufficient to allow tracking. When K1903 is deenergized, 28 volts is coupled across the relay contacts 12 to 11 and is an output at J1907 to the indicator video unit as a lockon signal.

The delay line driver output is a 1-μsec pulse. This pulse is the output of the coincidence circuit, which has been differentiated and amplified. The 1-μsec pulse is applied to the delay line DL1901, which has a 0.5-μsec delay. Remember, any signal applied to this delay line will require 1-μsec to travel down the line and back again, using 0.5-μsec in each direction. This means that when the signal returns (1 μsec later) the original signal has passed (in time) and the reflected signal which is inverted, will cause the waveform to continue (in time) forming the last half of the composite bipolar video waveform as illustrated. The entire bipolar video waveform is 2 μsec in duration.

Next, the bipolar video is applied to the error detector gate, which is formed of diodes CR1907 through CR1912. Note that a pair of 1-μsec gates, from gate driver Q1907, is also applied to the error detector gate at the same time. These gates have been delayed approximately .8-μsec by DL1902 and the transit time of the gate driver. The duration of these gates is 1-μsec; therefore, the error detector gate is open for 1-μsec. If the bipolar video signal is present and is centered in the gates, an equal portion of the video composite signal is gated through the error detector and the output is zero. If the target should move (in range), the gates will appear earlier or later, and the bipolar video will not be centered in the gate. The output of the error detector will now be either positive or negative, respectively.

These error voltages, during automatic track, represent the range changes of the target and indicate an error between the target and the tracking gate. The gates then must be moved in order to track the target. This operation is accomplished by the range voltage change, which is returned to the range comparator from the range integrator across K1901 and R1988. For example, if the range of the target has decreased, range voltage out at the range integrator will decrease; this decrease is felt at the range comparator as the range sweep voltage sawtooth will require less time to overcome the range voltage now at the junction of CR1926 and R1988, triggering the range strobe generator earlier. The range strobe will appear earlier, and the composite video pulse will again be centered in the tracking gate. Range voltage out is also used to operate the breakaway switch Q1927, which produces a signal for the breakaway circuits in the indicator display unit. Finally, the range of the target is an output at J1907-9 and is used in the indicator video unit.

Antenna azimuth and elevation error tracking signals are also detected in the tracking chassis. These voltages are obtained by detecting the amplitude modulation of the target signal and by comparing the phase of this modulation on the input target video pulses with a reference signal. Target video that was applied to the AGC bus is also applied to emitter follower Q1915 which detects the amplitude modulation carried by the input target video pulses. The detected modulation is then applied to the elevation and azimuth phase detectors. The amplitude modulation represents the radial error between the target and the antenna, and is phase compared with the reference voltage. The reference voltage is the target generator nutation signal applied to the phase detectors through J1903 and J1904. The output of the phase detectors is a d-c voltage whose polarity indicates direction of the error, and whose amplitude represents the amount of error. These outputs are then applied to the appropriate antenna tracking circuits.

The block in the illustration labeled test signal generator simply provides a signal for the tracking unit during maintenance and bench testing. To operate the test generator S1902, the test normal switch, is activated.

ANTENNA AND ANTENNA CONTROL

Since an antenna positioning servosystem was described in detail in chapter 6 of this manual, the antenna is only briefly discussed in this chapter. During the discussion refer to figure 12-21, which is a block diagram of the antenna and antenna control.

The antenna unit consists of control transformer B852, synchronous motor B851, a gear reduction arrangement, and the reflector and feed horn assembly. This group is shown on the right side of the illustration. The synchronous motor provides driving power to rotate the antenna in azimuth when it is energized by the signal from the magnetic amplifier T1802 in the antenna controller. The gear reduction provides the necessary reduction required to drive the antenna at the automatic rate of 6 rpm. The control transformer is mechanically connected to the antenna through the gear reduction arrangement at a ratio of one-to-one; thus it continuously samples antenna azimuth position, and feeds this signal back to the demodulator T1801. This signal is an error signal, which is compared with the command input.

The antenna control group (fig. 12-21) consists of synchronous motor B1801 (constant speed scan motor) and synchro generator, demodulator T1801, driver amplifier, magnetic amplifier T1802, a power supply, and necessary controls and switches. These items are shown in the center of figure 12-21. To the left of the control group is a portion of the indicator video unit. Recall that the antenna positioning servo and the scan pattern generator were part of this unit. Inputs to the antenna control group from the antenna position servo are shown as inputs to the demodulator T1801 and local remote switch S1802.

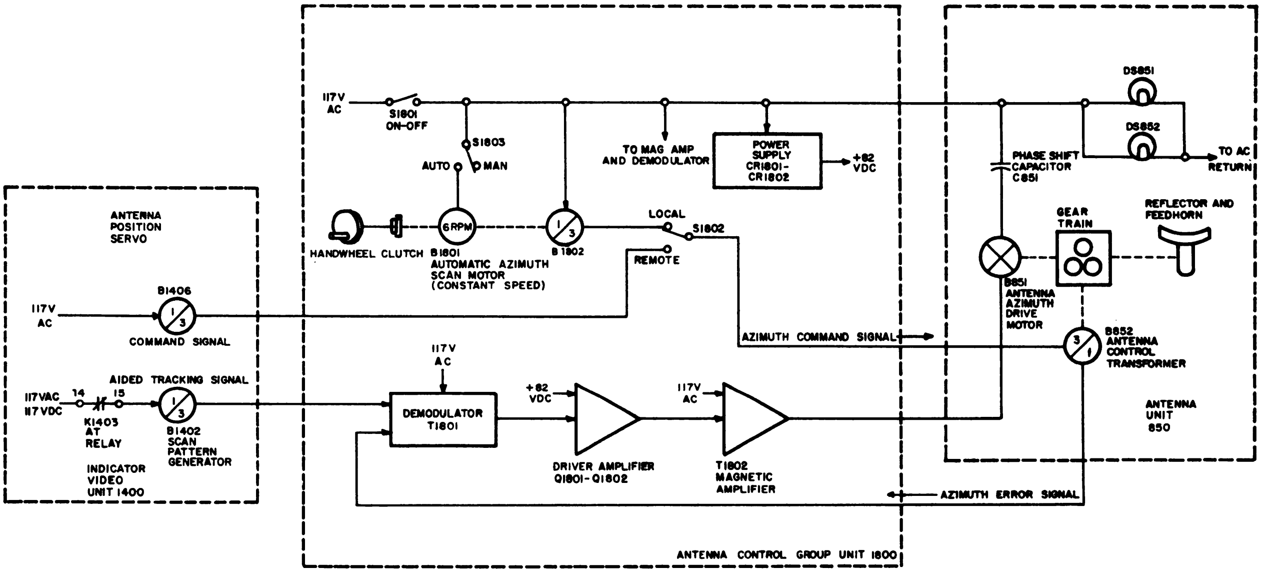

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Figure 12-21.—Antenna and antenna control block diagram.

Switch S1802 determines whether the azimuth command signal is taken from the antenna position servo or from the azimuth scan motor. If the local remote switch is in the position shown, and if the on-off switch S1801 is closed, the 117-volt a-c reference phase voltage is applied to the rotor winding of synchro generator B1802. This voltage induces in the stator winding a voltage whose phase and amplitude depend upon the angular displacement between the rotor and stator windings. The stator of the synchro generator is connected in parallel with the stator winding of synchro transformer B852 in the antenna unit so that the same signal voltage is present in the stator windings of each synchro. Since the rotor winding of B852 is mechanically linked to the antenna drive gearing, its position represents the position of the antenna. The voltage induced in the rotor of B852 represents the difference between the position of the antenna and the command signal generated by B852, and is the error voltage.

This error voltage is applied to demodulator T1801 where it is compared with the reference-phase voltage. An output signal is produced by T1801 whose amplitude and polarity are determined by the relative phase difference between the error voltage and the reference voltage. The output of T1801 is applied to a driver amplifier, operated push-pull, and is then coupled directly to magnetic amplifier T1802. In the magnetic amplifier, the signal is rectified and used as a d-c bias voltage to bias the saturable reactor along its hysteresis curve. Effectively, the error voltage from the demodulator is used to vary the inductance of the magnetic amplifier. This controls the amplitude and polarity of the magnetic amplifier output, which is then applied across a sensitivity control and used to drive the antenna azimuth drive motor. Note also that the reference phase voltage is fed to B851; this is applied to the fixed phase winding of the azimuth drive motor. S1803 in the antenna control is used to determine whether the command signal is automatic or manual.

Setting the local remote switch to remote allows the synchro generator in the antenna servo to assume command of antenna rotation. If the system is operating in the automatic search submode of fire control, an additional signal is applied to the demodulator. This signal is called aided tracking signal. Recall that during automatic search in fire control, sector scan is used; therefore, an increase in the driving signal is required to overcome the inertia and velocity effects of the antenna which would occur during sector scan rates in fire control search operation.

ANTENNA STABILIZATION PLATFORM

The purpose of stabilization is to isolate the antenna from motions of the aircraft. The motions that would destroy the effectiveness of an attack on an airborne or surface target are the roll and pitch of the aircraft as the pilot maneuvers into a position so that he could release a missile or drop a bomb. Figure 12-22 illustrates what happens when the motions of the aircraft have not been compensated.

Stabilization in an operating radar is required during search and acquisition operation. After radar lockon, the position of the antenna is slaved to the target tracking circuits and antenna position servo. These circuits continuously move the antenna, and at the same time provide information for steering, which is placed on the indicator as described previously. During search operations, the search pattern is stabilized to prevent loss of the target. In an actual radar, position signals are derived from the gyros which are normally a part of the stabilization platform. These signals are fed to the antenna servosystem to displace the antenna scan position when the aircraft deviates from the straight and level flight attitude. When the aircraft is banked (roll), the antenna is moved (tilted) in the opposite direction the same amount, thereby maintaining the scan parallel to the horizon. Similarly, when the aircraft climbs or dives (pitch), the antenna is raised or lowered (tilted) to maintain the elevation position with respect to the horizon as set by the pilot. Combined roll and pitch maneuvers result in a corresponding displacement of the antenna scan in the opposite direction. Thus, the position of targets on the scope is changed only by a change in relative azimuth-bearing and range. The effect of an aircraft in banking and climbing maneuvers with no stabilization is illustrated in (B) and (E) of figure 12-22. Note loss of the target on the scope. Parts (C) and (F) illustrate the same maneuvers, but with stabilization.

Since the antenna scan and the artificial horizon line are positioned by the same signal, displacement of the scan can be visualized by observing the artifical horizon line. For

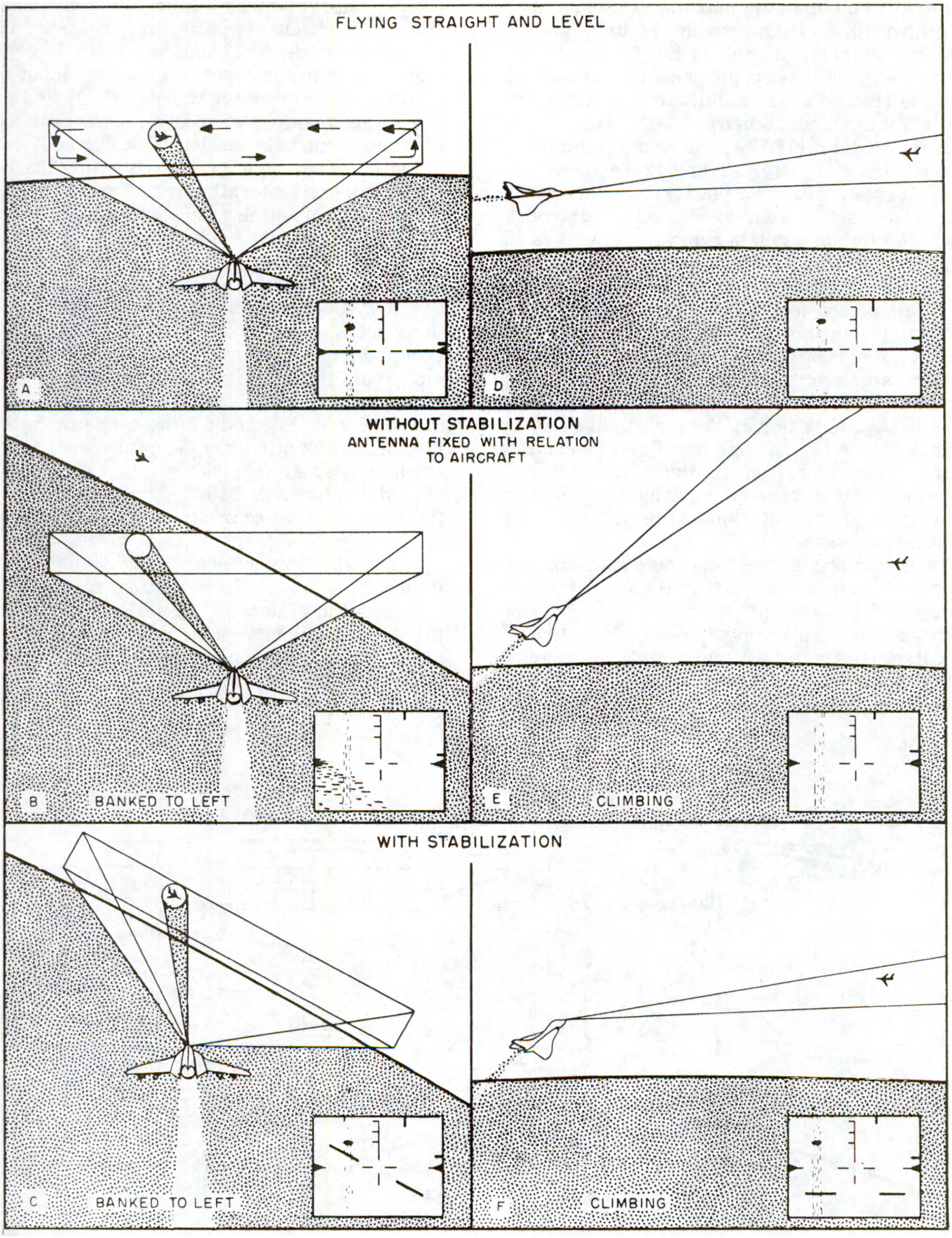

Figure 12-22.—Effect of antenna stabilization. AQ.492

mapping or bombing, the antenna is tilted slightly downward to pick up ground returns and the indicator displays a map of the forward area. After the pilot has positioned the antenna to scan the desired area, stabilization to that position is maintained as before. (See fig. 12-23.)

In the trainer 11D13A, roll and pitch motions are inserted manually. Figure 12-24 illustrates the trainer stabilization platform. When either gimbal is upset, a gear arrangement driven by separate pitch and roll servosystems drives the respective gimbals back to the horizontal. The servosystems, both azimuth and elevation, are identical except for one operation; because of mechanical limitations, the elevation functions (tilt) are incorporated in the pitch-stabilization system as shown in the upper left corner of the diagram. The inputs shown here are electrical, and will have no effect on the stabilization of the antenna, since to stabilize requires mechanical inputs. The operation of the pitch servo is described in the following paragraphs; roll is not described since the operation is practically identical.

Referring to figure 12-24, note that the pitch error signal is developed at R1006. R1006 is referenced to the roll gimbal by being firmly mounted on the roll gimbal frame. The input is indicated as aircraft pitch, which in an actual stabilization system would be an output from a pickoff of a gyro.

Any movement of the wiper arm of R1006 results in either a positive or negative voltage picked off between -25 and +25 volts d-c This, then, is the error signal, and is an input to the platform servosystem across R1007 and R1009 to the servoamplifier A1002. A second output is taken from between R1007 and R1009, and is the pitch error signal for positioning the target which is being generated by the target generator. A third signal is the pitch signal to the vertical gate in the indicator display unit.

Between the amplifier and the drive motor are four switches. These are limit switches S1006 through S1009. S1006 and S1007 protect the gimbal mechanism when the extremes are reached, and S1008 and S1009 prevent the operator from injecting a combined error in pitch and tilt of more than 45°. Pitch malfunction switch S1005 is used by the operator to simulate a malfunction in the pitch servosystem. During normal operation, all switches are closed, and motor B1002 drives potentiometer R1011 back to its original position. At the same time the worm gear is also driven, which will operate the sector gear that is mechanically linked to R1006. This motion returns R1006 and the pitch gimbal to the null position. During the erection period, potentiometer R1011 also produces a feedback to the amplifier which is in opposition to the error input. During manual track, or nod inputs, feedback is from the

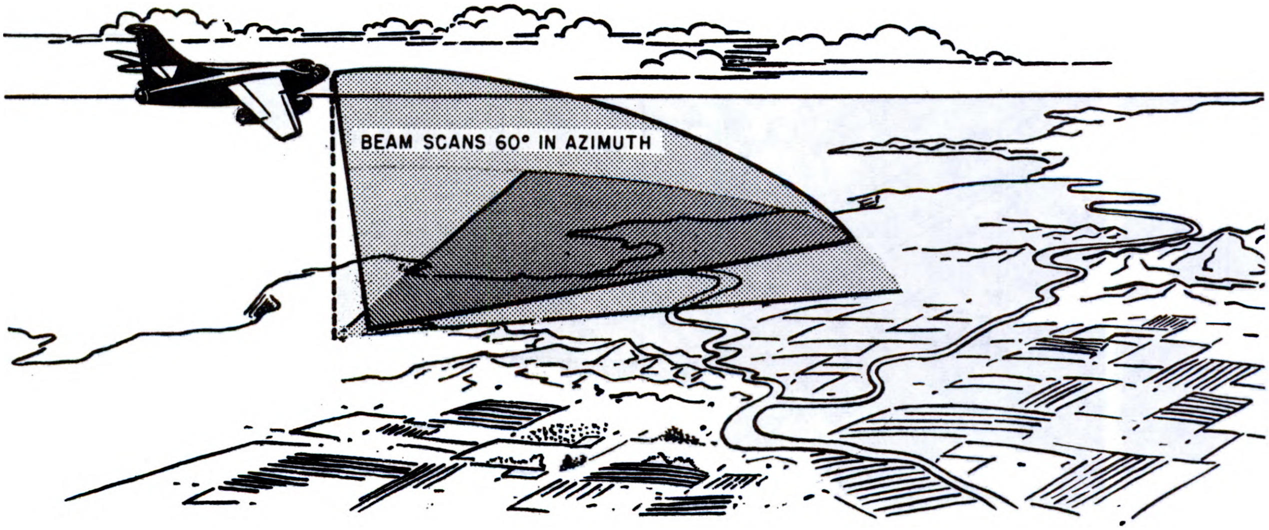

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Figure 12-23.—Antenna scan for mapping and bombing.

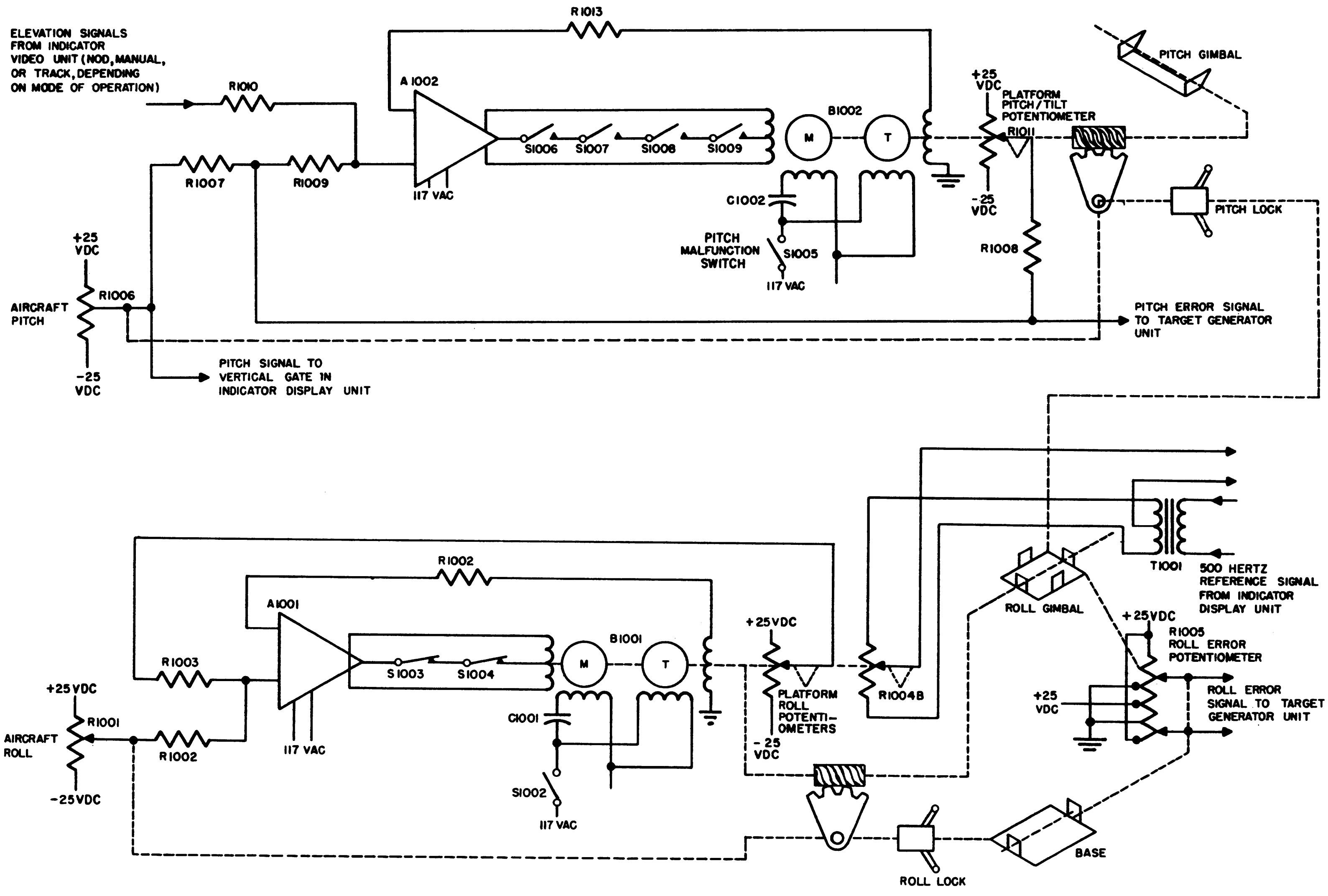
ELEVATION SIGNALS FROM INDICATOR VIDEO UNIT (NOD, MANUAL, OR TRACK, DEPENDING ON MODE OF OPERATION)
R1010
R1013
A1002
R1007
R1009
117 VAC
S1006
S1007
S1008
S1009
B1002
M
T
C1002
PITCH MALFUNCTION SWITCH
S1005
117 VAC
+25 VDC
AIRCRAFT PITCH
R1006
-25 VDC
PITCH SIGNAL TO VERTICAL GATE IN INDICATOR DISPLAY UNIT
+25 VDC
PLATFORM PITCH/TILT POTENTIOMETER
R1011
-25 VDC
R1008
PITCH GIMBAL
PITCH LOCK
PITCH ERROR SIGNAL TO TARGET GENERATOR UNIT
R1002
A1001
R1003
+25VDC
AIRCRAFT ROLL
R1001
R1002
-25VDC
S1003
S1004
117 VAC
B1001
M
T
C1001
S1002
117 VAC
+25VDC
PLATFORM ROLL POTENTIOMETERS
-25 VDC
R1004B
ROLL GIMBAL
T1001
500 HERTZ REFERENCE SIGNAL FROM INDICATOR DISPLAY UNIT
+25VDC
R1005 ROLL ERROR POTENTIOMETER
+25 VDC
ROLL ERROR SIGNAL TO TARGET GENERATOR UNIT
BASE
ROLL LOCK
AQ.494

Figure 12-24.—Antenna stabilization platform.

generator across R1013 to cancel out the original input, when the antenna has reached the desired tilt position. During this time, R1011 feeds back to cancel the input from R1006.

SYSTEM TESTING

In the field of radar, reliance cannot be placed solely on scope interpretation by the technician to judge the range capability and data accuracy of radar systems unless BIT checks are used. It has been found to be so inaccurate as to be completely valueless. Numerous tests in the field strongly emphasize this fact. In one instance, the performance of approximately 100 different radar sets was carefully measured with test equipment of known accuracy. In each case, the radar set under test was considered to be in normal operating condition by the radar personnel involved. The results of these tests revealed that, on the average, the maximum effective range of the radar equipments under test was only one-half the maximum range possible, had the equipment been operating at peak efficiency. In fact, five radar sets were found to be operating at less than 10 percent of their maximum range, which means, in effect, that these radar equipments were protecting only 1 percent of their assigned tactical areas. Since such poor performance, as demonstrated by these tests, may have serious consequences, it can readily be seen that performance testing is of the utmost importance in radar work. An investigation to find the cause of this unsatisfactory situation showed that many technicians are not sufficiently familiar with the techniques and procedures necessary to test microwave radar systems properly.

Radar performance testing involves a series of measurements which are primarily intended to indicate the ability of the radar to detect targets. The combined results of the tests then indicate the overall radar performance. Two distinct and separate factors are involved in the consideration of radar performance: (1) minimum range performance; and (2) maximum range performance.

MINIMUM RANGE PERFORMANCE

The TR recovery time and the transmitter pulse width are important factors in determining the effective minimum range. If a target has a range of 200 yards, the echo is returned to the radar in about 1-1/4 microseconds after the occurrence of the transmitter pulse. If the receiver is to respond to this echo, the TR switch must recover sufficiently during this short interval to allow passage of energy to the receiver. Since a nearby target returns a strong signal, the recovery need not be complete. The receiver responds to a strong signal even at reduced sensitivity.

Minimum range performance is also influenced by the transmitter pulse width. Long range search radar facilities may use a pulse width of 2 microseconds or greater, which represents a free-space range of over 320 yards. Radars designed for close range work have pulse widths as short as one-quarter microsecond, which represents only a little over 40 yards of free-space range. Minimum range performance is also discussed in chapter 10 of this manual.

MAXIMUM RANGE PERFORMANCE

The factors which determine the maximum range of a radar are rather diverse. However, for the purpose of the discussion to follow, they may be divided into two general categories. The first category, which is not controllable by the maintenance activity, consists of target reflection and propagation factors. The second category is made up of performance factors, which are controllable to some degree by the maintenance activity.

Target reflection is a direct function of target size. Four principle factors which enter into the determination of the amount of energy reflected by a radar target are as follows:

1. The material of which the target is constructed.
2. The surface area presented to the radar.
3. The configuration of the surface presented to the radar.
4. The operating frequency of the radar.

In general, it can be said that the amount of energy reflected from a target is a very complex consideration, and that the reflected signal energy cannot be predicted with any degree of accuracy. Therefore, when information on the reflected-signal strength is required, it is best found by direct measurement.

Atmospheric conditions play a very important part in radar performance. Some of the more common factors are as follows:

1. Duct formation.
2. Temperature inversion and atmospheric refraction.

3. Rain echoes and scattering.
4. Atmospheric absorption.

Atmospheric conditions relating to radar operation are covered in chapter 10 of this manual.

Maximum range performance also depends upon the condition of the radar. Radar condition is the only factor which may be controlled to some degree by maintenance, and therefore is the most important. Radar equipment performance is dependent upon such items as transmitter power, frequency, and spectrum, receiver bandwidth and sensitivity (mds), TR recovery time, and AFC operation. These items are all covered in chapter 19 of this manual.

Testing of complex weapon systems demands strict adherence to prearranged procedures as set forth in the appropriate maintenance equipments manuals. Indiscriminate alinement adjustments or testing must not be attempted. The technician MUST refer to and follow the approved procedures provided.

SYSTEM TROUBLE ANALYSIS

Technicians are generally given technical training in the equipment they are to maintain, but to be a proficient troubleshooter the technician must supplement this training in two ways: (1) he must learn to identify those faults in a radar set which can be located by simple observation; and (2) when faults cannot be located by these means, he must divide the radar set into operating systems and subsystems so that the faulty component can be quickly isolated.

With a few exceptions, all troubles which cannot be identified by a simple observation can be located by a logical process which breaks the radar set into major independent operating systems, and these systems in turn into subsystems. In so dividing the radar set, the technician can disregard the systems and subsystems which are operating properly and concentrate his troubleshooting on the elements which exhibit abnormal functioning, so that he gets directly at the source of trouble with maximum efficiency.

For this method of troubleshooting to be most effective, the technician must bear in mind several important considerations in the selection of systems and subsystems. The foremost of these considerations include the following:

1. The breakdown of a system into subsystems should be such that the tests required to determine the faulty subsystem are quick, direct, and easy to make.
2. The numbers of subsystems within any system must be kept low.
3. All the subsystems within a system should be selected as having approximately an equal change of failure.
4. Systems and subsystems not related to the trouble being traced should not be included at the same level of importance as those regarded most probably at fault. As the technician develops a growing technique of logical breakdown, his ability to isolate and identify troubles quickly and correctly will grow in proportion.

MAINTENANCE BY EXCEPTION

All maintenance is related to some form of management. The function of management has been defined as "the efficient attainment of enterprise objectives." Maintenance has also been defined as "all actions taken to retain material/equipment in a serviceable condition or to restore it to serviceability." When these are combined, we can define Maintenance Management as "the actions necessary to retain/restore material/equipment in a serviceable condition with a minimum expenditure of resources." Resources are commonly referred to as men, money, and material.

Maintenance by exception is fundamental to this entire management system. It means simply that actions or incidents which vary markedly from established standards or norms are singled out as exceptions from the whole for special management attention. For example, if certain black boxes within a weapons system consistently fail to produce the desired results, then they would be singled out for special study and corrective action. Since the normal would be correct operation and these black boxes were chronically failing and consuming abnormal numbers of man-hours, they would be considered an exception.

CHAPTER 13

ANALOG COMPUTATION

A computer is a device that performs mathematical calculations on input data to yield new and generally more useful results. The first computer, an abacus, was used by the ancient Greeks and Romans. It is a simple kind of manually operated device utilizing sliding beads; if operated according to definite rules, it can perform addition and subtraction very rapidly. Computers found in use today range from the mechanical adding machine and slide rule to room-sized complex devices commonly referred to as brains.

The development of the computer probably contributed more to the advancement of today's weapons systems than any other single factor. Without the use of such complex machines, solution of today's weapon control problem would be impossible.

Analog computers are best employed where continually varying solutions are needed for problems whose factors are continuously varying. These factors generally are physical quantities, such as velocity, direction, or range. Such physical quantities are most conveniently represented by degrees of shaft rotation, magnitude or phase of a voltage, or the speed and direction of movement of some mechanical part. The varying instantaneous summation, or simultaneous solution, of outputs from all the computing parts comprises the computer's output.

This output may then be applied as needed, depending on the purpose of the computer. For instance, in a fire control computer, the output positions a weapon sighting reticle in relation to the direction of flight. As the pilot maneuvers to keep an enemy target within the reticle, the weapons are properly aimed. In a bombing computer, the output releases bombs at the proper time, and is used to drive indicators which give the aircraft's position at all times in latitude and longitude. The accuracy of the analog computer is determined by the percentage errors of the devices used, multiplied by the maximum quantity of the input variables.

COMPUTER CLASSIFICATION

The main division between computers is whether they be either digital or analog. However, they may be classified further by considering their construction as follows:

1. Electronic
2. Electromechanical
3. Mechanical

Electronic computers utilize electrical units, such as voltage amplitude and phase, resistance, electrical impulses, and other electrical units to represent physical quantities. Computers of this type usually contain electronic and magnetic amplifiers, phase detectors, modulators, and demodulators. Chapter 15 of this manual briefly describes the operation of a computer of this type.

Electromechanical computers represent numbers or variables in both electrical and mechanical units. A typical application may employ both electrical and mechanical inputs to a servomechanism and may have a mechanical output.

Mechanical computers utilize mechanical quantities to represent the input and output values. They normally contain devices that add, subtract, multiply, or divide by means of gear ratios, shaft rotations, etc.

Mechanical computers were used in bombing systems developed after World War II. However, they have been replaced in aviation weapons systems by more complex, but more accurate computers. (Mechanical computing devices are discussed in Basic Machines, NavPers 10624-A.)

In actual practice, computers used in aviation weapons systems are not normally of any one type, but contain some features of all types. Their classification is based on the predominant type of computing device found in the equipment.

COMPUTATION PRINCIPLES

There are a number of requirements which an airborne analog computer must fulfill. Primarily, it must possess sufficient accuracy to solve a problem within the required limits. It must be constructed in a manner whereby it can withstand the stresses of airborne use and require a minimum of maintenance. It is also advantageous from the maintenance standpoint for a computer to use as many similar components as practicable, keeping the number of spare parts to a minimum. This requires the rearrangement of equations from their simplest form to one that is more complicated for reasons not readily apparent to the technician. Many computers have been designed around equation rearrangement.

EQUATION REARRANGEMENT

The equation below represents a typical problem to be solved within a computer.

$$J = \frac{Rt_f}{R_f}$$

The factor J is a mathematical quantity determined by the factors R (present range of airborne target), t_f (time of flight of the projectile), and R_f (future range of the target). The quantity J has no significant meaning other than that it represents the term $\frac{Rt_f}{R_f}$ in the above equation. One method of solving this problem requires the use of a servosystem.

As should be recalled, the operation of a servomechanism is dependent upon its ability to compare two quantities and feed an error signal to its output device, which, in turn, causes the error signal to be canceled. The servosystem may be utilized to give a continuous solution to the problem if the formula is rearranged to give a zero output. By multiplying both sides of the above equation by $\frac{R_f}{Jt_f}$ and transposing, the equation can be written as follows:

$$\frac{R}{J} - \frac{R_f}{t_f} = 0$$

Another example of equation rearrangement involves the use of logarithms. A computer problem may involve the multiplication and division of several quantities. Referring again to the equation

$$J = \frac{Rt_f}{R_f}$$

it can be arranged as follows:

$$\log_{10}J = \log_{10}R + \log_{10}t_f - \log_{10}R_f$$

The logarithm of each quantity may be found electronically by the use of specially designed networks. (These networks are discussed later in this chapter.) When the equation has been changed into the logarithmic form, the computing is accomplished by simplified addition and subtraction of the quantities. Magnetic amplifiers are especially well suited for solutions of this type.

The results of logarithmic computation frequently can be used in the logarithmic form. However, the antilogarithm may also be found by use of a network giving an answer to the problem in the same form in which it was originally stated.

IMPLICIT SOLUTION

The use of computers to solve complex problems does not always afford direct solution to all parts of the problem. Thus, the solution may be based on indirect or implicit methods.

Implicit problem solving may accomplish subtraction by means of addition, division by means of multiplication, the extraction of a square root by means of squaring, and differentiation by means of integration. The following is a comparison of explicit and implicit methods of problem solving:

	EXPLICIT	IMPLICIT
Subtraction . . .	$c = a - b$	$c + b = a$
Square root . . .	$c = \sqrt{a}$	$c^2 = a$
Division	$c = a/b$	$cb = a$

The use of the implicit function technique is found frequently in aviation fire control computers. There are numerous computations for which the implicit method may be more accurate or more convenient, based on the information available to the computer. Servomechanisms and amplifiers utilizing negative and positive feedback are well suited for instrumentation of implicit operations.

QUANTITY REPRESENTATION

For the purpose of this chapter, representation of quantity may be defined as that physical quantity used by an analog computer to represent a specific input quantity. Thus, for example, a specific quantity, range from the gun platform to the target aircraft, may be identified with a d-c voltage fed to the analog computer for solution of the problem.

IDENTITY OPERATIONS

For the purpose of this discussion, an identity operation may be defined as any operation that does not change the mathematical quantity represented. Examples of identity operations are changes in scale factor, voltage level, impedance, and data representation.

Change in Scale Factor

Before discussing a change of scale factor, let us first define scale factor. In an analog computer, the scale factor is the ratio of the analog unit to the equation unit. Thus,

$$\text{scale factor} = \frac{\text{analog units}}{\text{equation units (physical)}}$$

Any change in analog units without a corresponding change in equation units will result in a change in scale factor. To illustrate this, consider the following example:

A 10-volt positive d-c signal is selected to represent a range of 1,000 yards.

$$\text{scale factor} = \frac{+10 \text{ volts}}{1{,}000 \text{ yards}}$$
$$= 0.01 \text{ volt per yard}$$

If the 10-volt signal is fed through a d-c amplifier having a voltage gain of 10, the analog unit is now equal to 100 volts. The scale factor is:

$$\text{scale factor} = \frac{+100 \text{ volts}}{1{,}000 \text{ yards}}$$
$$= 0.1 \text{ volt per yard}$$

Thus, the scale factor was changed by the action of the amplifier.

When the multiplier is less than one, simple networks of resistance, capacitance, or inductance may be used. When the constant of multiplication is greater than one, amplifiers whose gain has been accurately calibrated may be used.

Change of Voltage Level

Computers, such as those utilizing addition and subtraction, must frequently change or shift the voltage level or reference to that level usable by subsequent components or units. A possible example of a shift in voltage level is found in direct-coupled amplifiers where the equipment is limited by the output of the d-c supply for the amplifier.

Change of Impedance

A change in output impedance may be required to match the various sections of a computer. This may be accomplished by the use of networks, and in some cases the use of cathode followers or other amplifiers employing feedback.

LINEAR FUNCTIONS

A linear function in mathematics is one that can be shown by a straight line on rectangular graph paper. Linear functions include those functions that involve summation (addition and subtraction), multiplication, and division, but not those that involve squares, square roots, trigonometric functions, and logarithms.

SUMMATION

The process of summation can be accomplished with electrical, mechanical, or electromechanical devices. Voltages are added, motions are added, or voltages and motions may be combined to give an output proportional to their inputs.

Electrical Summation

To simplify the presentation, both electrical and electronic summing devices will be discussed under this heading. The first device will be the series circuit in which the output voltage E_0 is simply the series addition of the input voltages E1 and E2.

$$E_o = E1 + E2 \qquad (1)$$

Only one of the input voltages can be grounded. Any others must be isolated from ground. This is illustrated in figure 13-1. Note that the secondary of the transformer is ungrounded, while the voltage E1 is from a grounded source. Isolating transformers must be carefully designed to minimize capacitive coupling from primary to secondary winding, which would cause phase shift variations.

Series adding is primarily used when voltage sources are inductive units, such as synchros, tachometers, resolvers, etc., already isolated from ground. Series summation is also used when the attenuation of parallel summation networks cannot be tolerated.

When subtracting two a-c voltages by this method, they should be 180° out of phase for correct results. Combining voltages that are not in phase or 180° out of phase results in a quadrature voltage and consequently an error in the output.

If d-c voltages are to be added in series, transformers cannot be used and a separate d-c power supply is required for each term or input to obtain isolated sources of voltage.

It should be remembered that the methods presented in this chapter are basic, and many variations of these methods will be found in equipments.

A parallel resistance network can also be used to electrically produce the algebraic sum of several input voltages. Voltages E1 and E2 are connected in series with two resistors R1 and R2 and terminated at a common junction as shown in figure 13-2. The voltage E_0 is not the actual sum of the input voltages, but is proportional to that sum.

Using the values given in figure 13-2, it can now be proved that the output voltage E_0 is proportional to the inputs. If the voltage E_0 feeds into an infinite impedance, there is no load current. The circuit may now be considered as a series circuit, with

$$I1 = I2 \qquad (2)$$

Then, since all branches are parallel,

$$E1 + I1R1 = E2 - I2R2 = E_o \qquad (3)$$

Solving the currents in each part of equation (3) and substituting the results into equation (2),

$$\frac{E_o - E1}{R1} - \frac{E2 - E_o}{R2} = 0 \qquad (4)$$

Solving equation (4) for E_0,

$$E_o = \frac{\frac{E1}{R2} + \frac{E2}{R2}}{\frac{1}{R1} + \frac{1}{R2}} \qquad (5)$$

or, by further simplification,

$$E_o = \frac{R2E1 + R1E2}{R2 + R1}$$

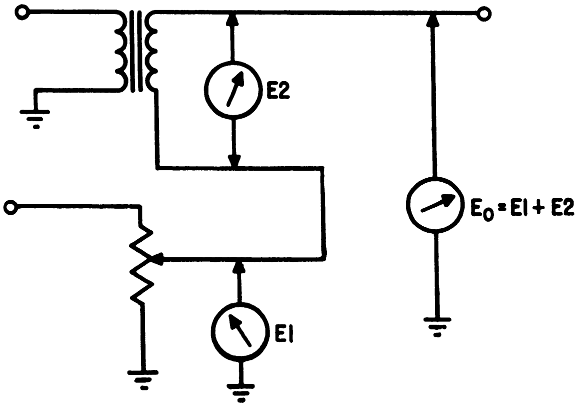

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Figure 13-1.—Series addition.

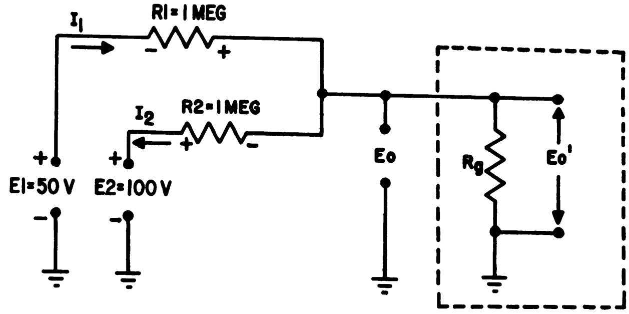

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Figure 13-2.—Parallel summation network.

Thus, an expression for voltage E_O has been obtained in terms of the sum of the two input voltages and their respective series resistors.

The voltage E_O was obtained above by assuming a very high-impedance load. If a grid resistor R_g is included, the voltage E_O is determined by:

$$E'_o = E_o \times \frac{R_g}{\frac{R1\ R2}{R1 + R2} + R_g}$$

As pointed out previously, the voltage output is not the actual sum of the input voltages, but is proportional to that sum. The following example illustrates this proportionality:

E1 = 50 volts	E2 = 100 volts
R1 = 1 megohm	R2 = 1 megohm

Then, using equation (5),

$$E_o = \frac{\frac{50}{1 \times 10^6} + \frac{100}{1 \times 10^6}}{\frac{1}{1 \times 10^6} + \frac{1}{1 \times 10^6}}$$

$$E_o = \frac{150}{2} = 75 \text{ volts}$$

If E_O were the actual sum of the input voltages, the voltage output would be 150 volts. However, this difference in actual sum and proportional voltage can be compensated for by a change in scale factor.

When a difference between two terms is required (subtracted), a negative voltage is used to represent the quantity being subtracted (the subtrahend). Both the negative and positive voltages are fed to the parallel resistance network as previously discussed.

Scale Factor

Although addition has been explained as a summation of voltages, the computer's real job is to add physical units, such as feet per second or degrees per minute. The proper application of scale factors makes the addition of physical units of an equation possible. The following transformation formula is used for this purpose:

Equation units x scale factor = analog units

When the physical inputs to the analog computer are represented by voltages, the final solution in the proper units can be found only by dividing the summed voltages by the output scale factor. If the voltage E1 and E2 in figure 13-3 were chosen to represent 1,000 feet each, the scale factor for the input voltages would be 1 volt per 10 feet and should be written as 1 volt/10 feet.

If the output physical units are to equal the sum of the input physical units, the scale factor at the output must be 1 volt/20 feet. By using the transformation formula, the sum of the physical units is obtained as follows:

$$2{,}000 \text{ feet} \times \frac{1 \text{ volt}}{20 \text{ feet}} = 100 \text{ volts}$$

In the examples discussed previously, the input scale factors were identical. Consider the operation of the summing circuit shown in figure 13-4 if the input scale factors are different. In the equation, $D_t = D1 + D2$, D1 has a scale factor of 1 volt/10 feet and D2 is represented by the scale factor 1 volt/5 feet. Since the physical units per volt of the scale factors must add directly, the output scale factor is 1 volt/15 feet. This result is obtained by thinking in terms of units per volt (reciprocal of scale factor) for the addition operation. Direct addition of the scale factors for D1 and D2 would not result in the desired addition of physical units, because the scale factor definition places the physical units in the denominator.

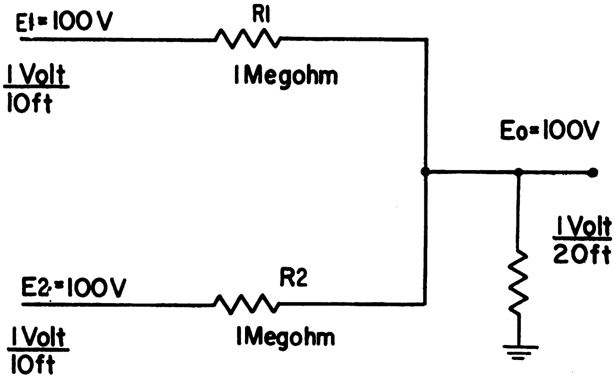

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Figure 13-3.—Scale factors assigned to parallel resistor summation networks.

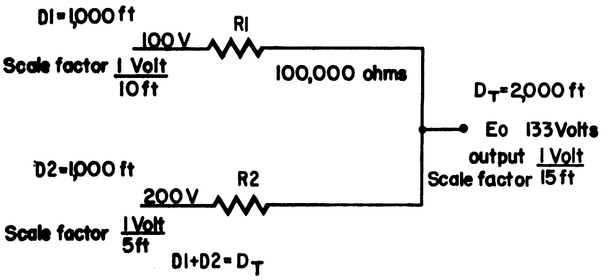

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Figure 13-4.—Addition with unequal scale factors.

From the example in figure 13-4, the correct answer for D_t is 2,000 feet. What values of R1 and R2 will supply the answer if the analog unit at the output is known and the output scale factor is known? The analog unit is obtained by substituting in the following formula:

$$\begin{aligned} \text{analog unit} &= \text{equation unit} \times \text{scale factor} \\ &= 2{,}000 \text{ feet} \times \frac{1 \text{ volt}}{15 \text{ feet}} \\ &= 133 \text{ volts} \end{aligned}$$

Referring to equation (6), it is apparent that R1 cannot equal R2 as in the previous example. It is permissible to select one resistance value arbitrarily; consequently R1 may be set equal to 100,000 ohms, a typical value. Substituting known values in equation (6) and solving for R2:

$$133 = \frac{(R2 \times 100) + (100{,}000 \times 200)}{100{,}000 + R2}$$

$$R2 = 200{,}000 \text{ ohms}$$

The Aviation Fire Control Technician will not be expected to compute component sizes or scale factors. However, it is of the utmost importance that he have a thorough understanding of scale factors in order that he may understand what is being accomplished in each stage of a computer and also how it is being accomplished.

Electronic Amplifiers Used for Isolation

In analog computers it is not always possible to apply the output of parallel resistor summation networks directly to subsequent circuits without getting nonlinear results because of loading. Loading is avoided by using an isolation amplifier with a high-impedance input and a low-impedance output between the summation network output and the succeeding computer component.

Since the signal magnitude is the computed quantity, the gain of these isolation amplifiers must necessarily be quite accurately maintained. The gain of any amplifier, of course, is affected by such things as a weak tube, a shift in power supply voltage, temperature changes, etc. The proper use of negative feedback is quite effective in solving this problem. Since a large amount of negative feedback is required if the full advantage of feedback stabilization is to be obtained, high-gain amplifiers are needed in such circuits. The gain of the amplifier itself does not affect the overall circuit gain because of the negative feedback. Figure 13-5 shows the basic circuit employing an isolation amplifier.

The amplifier output is fed back to the summing point G at the input of the amplifier through the feedback resistance R_f. Since the gain of the amplifier is extremely high, the voltage $-e_o/A$ at the summing point G is very nearly zero. (Recall that the value of any fraction whose denominator is extremely large approaches zero very closely.) Thus, the current through R_g is negligible. Assuming the amplifier input does not draw current (normally a very good assumption) and that the amplifier gain is high (that is, $1/A$ is much less than 1), the

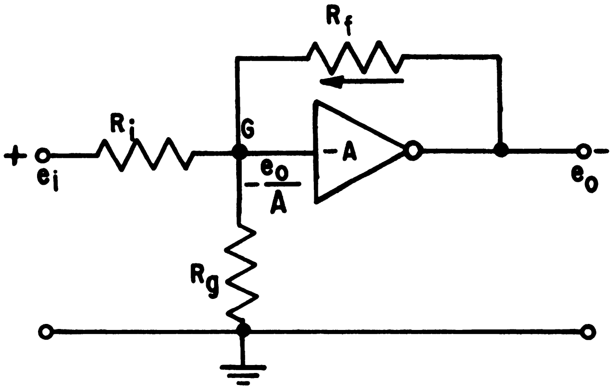

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Figure 13-5.—Basic isolation amplifier circuit.

current through R_i equals minus that through R_f, by Kirchhoff's current law at point G, or:

$$\frac{e_i}{R_i} = \frac{e_o}{-R_f}$$

Rearranging, to obtain an expression for gain:

$$\frac{e_o}{e_i} = \frac{-R_f}{R_i}$$

This is the basic equation which describes the operation of any circuit utilizing a high-gain amplifier with negative feedback. It is well worth remembering.

Thus, if $R_i = R_f$, the circuit gain is unity, and the circuit is quite effective as a precision isolation device. The loading which this circuit presents to its driving circuit is essentially R_i, since the voltage at point G is essentially zero.

If the amplifier gain deteriorates with age, there is some point at which the approximate expression for circuit gain no longer holds. A more exact expression which shows the effect of amplifier gain is

$$\frac{e_o}{e_i} = \frac{-R_f}{R_i}\left(\frac{A}{1 + A}\right)$$

This equation may be used to show that even if the amplifier gain is designed to be only 100, a reduction in gain to about 50 percent is required to reduce the circuit gain by 1 percent.

SUMMING AMPLIFIERS.—The high-gain d-c amplifiers described in the foregoing discussion are used in many applications where their isolation characteristics are needed. Typical of such application is their use in summing circuits where loading effects are serious. When used in this way, they are connected as shown in figure 13-6. The entire circuit, including the electrical summing network, the high-gain amplifier, and the feedback loop, is called a "summing amplifier."

Recall that the overall gain of the feedback amplifier circuit is determined by the ratio of feedback impedance to the total input impedance. When this ratio is 1 (both impedances equal), the gain of the amplifier circuit is unity and the circuit merely algebraically adds all the input voltages.

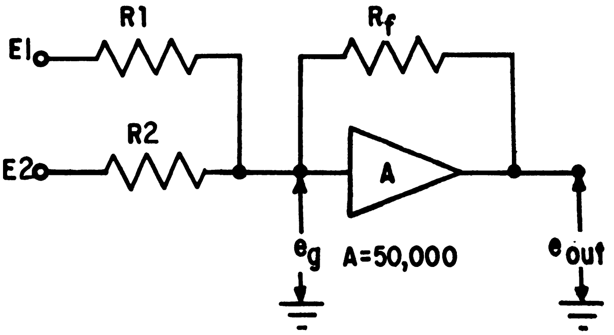

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Figure 13-6.—Summing amplifier schematic.

Practically speaking, the number of inputs to a summing amplifier are limited by amplifier saturation. A typical summing amplifier has an input voltage range from -50 to +50 volts and an output voltage range from -100 volts to +100 volts. This means that the total input voltage cannot exceed ±50 volts, and that the individual voltage inputs and gains must be such as to provide a total output that does not exceed ±100 volts. When these conditions are exceeded, amplifier saturation occurs and further linear amplification is impossible.

OPERATIONAL AMPLIFIERS.—By now it should be clear that almost any mathematical operation can be performed by suitable mechanical and electronic devices. Some of these operations have already been discussed. Others, including the calculus operations of differentiation and integration, will be discussed later in this chapter.

The use of high-gain d-c amplifiers has become commonplace in the performance of these operations; hence the term "operational amplifiers." This term will be used throughout the remainder of this chapter in a general sense, signifying any high-gain d-c amplifier which employs negative feedback.

Up to this point, we have assumed that the d-c amplifiers used in operational amplifiers can produce an output voltage that is an exact magnified version of the input voltage, but exactly 180° out of phase with the input. For a number of reasons, practical amplifiers fail to perform in this ideal manner.

The first reason is based upon the fact that the usual operational amplifier consists of three cascaded d-c amplifier stages with a combined open loop gain of 50,000, or 92 db. The closed loop gain (that is, the gain obtained when a feedback resistor that is equal in value to the input resistance is connected between the output plate and the input grid) is unity.

At the high gains used in these amplifiers, any spurious voltage variations that occur in the d-c amplifier stages may produce a considerable amount of undesired variation or drift in the amplifier output voltage. Drift shows up as a voltage imbalance that appears at the amplifier output terminals in addition to the correct output voltage. When it occurs in computer applications, this imbalance produces errors in the computation.

There are four main causes of drift. They are:

1. Power supply voltage variation.
2. Filament voltage variation or transistor bias variation.
3. Varying resistance values.
4. Varying vacuum tube characteristics or transistor parameters.

Other operational amplifier errors are caused by seemingly insignificant currents and voltages such as leakage currents, voltage drops in ground loops, and grid currents. The resulting currents are in the order of fractions of a microampere. Yet, these currents flow through the input resistors. A current of 0.1 microampere flowing through a 1-megohm resistor will generate an error voltage of 0.1 volt.

As shown in figure 13-7, if an assumed 0.2-volt grid-voltage change is produced by a filament-voltage change, an output voltage change of 200 volts is obtained even though the input signal voltage is zero. By means of a similar analysis it is possible to show that plate or collector supply voltage changes and cathode or emitter emission variations would all tend to increase the output voltage imbalance, and that they would produce the most serious effects when they occur in the first stage.

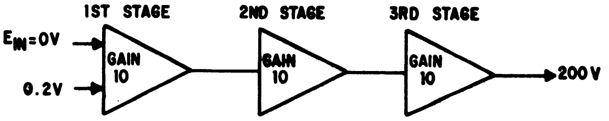

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Figure 13-7.—Amplification of three stages of gain.

Changes in transistor parameters, due to temperature variation, are the main cause of drift in transistorized d-c amplifiers. The most widely used drift reduction circuit is the differential amplifier (fig. 13-8). As the name implies, the output voltage (taken between collectors) is equal to the difference between the two input voltages. Any output variations caused by drift voltages are canceled because both transistors are almost equally affected and the difference voltage between collectors remains constant.

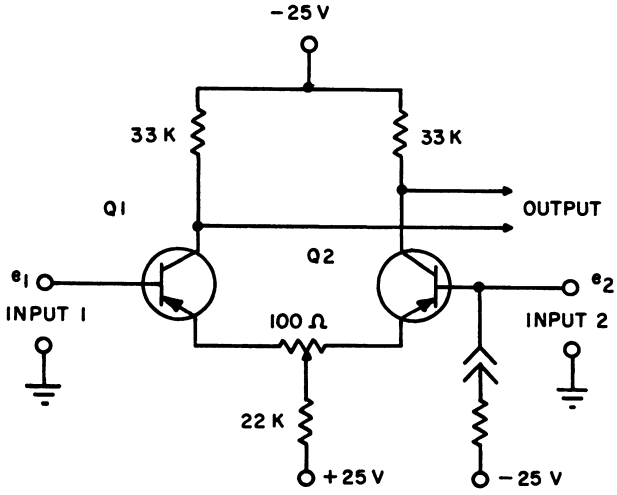

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Figure 13-8.—Basic differential amplifier

The circuit can be used either with two inputs or with one having a fixed bias. In either case, collector current drawn by one transistor affects that drawn by the other because of the common emitter resistor.

An increase in the collector current of transistor Q1, for example, increases the emitter voltage of transistor Q2. However, the base-to-emitter voltage of transistor Q2 will be decreased (if the base voltage is held constant) since the difference between the base voltage and emitter voltage appears there. Consequently, the base current of transistor Q2 decreases and the collector voltage increases. Since the collector voltage of transistor Q1 decreases, the difference voltage becomes greater.

The differential amplifier provides a gain determined by the current gain of each stage.

As one collector voltage is reduced, the other collector voltage is increased. The difference between the two collectors is much greater than the difference between the two input voltages because of the current gain of the two transistors. The high value of emitter resistance and voltage also provides a very high input impedance.

The potentiometer in the emitter circuit is used to adjust the circuit output voltage when no input is present; that is, by varying the emitter voltages of the two transistors, it is possible to select the values of quiescent base currents.

As previously mentioned, most operational amplifiers consist of a basic 3-stage d-c amplifier. The reason for using multiple stages is the need of obtaining high gain; the reason for using an odd number of stages is that we can thus obtain the required reversal of polarity between the input and output voltages. (Recall that negative feedback is used in the operational amplifier.)

Figure 13-9 shows a 3-stage d-c amplifier schematic which consists of two differential amplifiers and a conventional amplifier. Negative feedback is used within the amplifier to provide stable gains over a wide range of frequencies.

In negative feedback circuits, a fixed portion of the output voltage is fed back to the input and used to cancel out a portion of the input voltage or current. In some ways the feedback circuit consisting of R1 and R2 appears similar to the collector-to-base negative feedback.

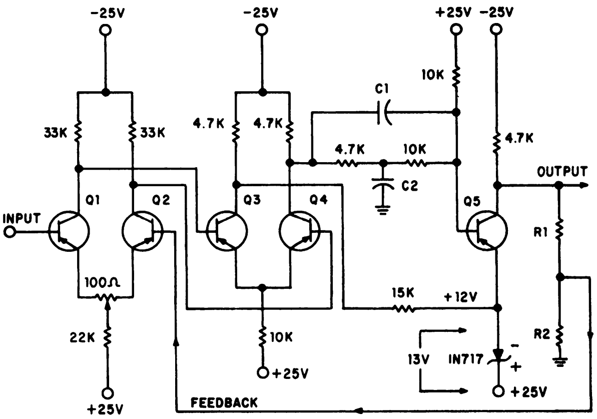

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Figure 13-9.—A three-stage d-c amplifier.

To function properly, the feedback and the output voltage of the overall amplifier must be exactly in phase with the input voltage and current.

Unfortunately, however, the input capacitances of each stage introduce time delays or phase shifts. These phase shifts depend upon the frequency components of the signal passing through the amplifier. Without some form of compensation, distortion would be produced as a result of subtracting two current waveforms that are not exactly in phase.

The resistor capacitor network applying base current to transistor Q5 provides the extra phase shift required to make the output voltage exactly in phase with the input voltage and current.

Electromechanical Summation

If the inputs or outputs of a summing operation cannot be physically brought together, a synchro system may be used. A chain of three synchro units consisting of a synchro transmitter, a synchro differential transmitter, and a synchro receiver adds or subtracts shaft rotations. If an output voltage rather than a shaft rotation is needed, the synchro receiver can be replaced with a synchro control transformer. Gear ratios may be added between the input shaft and the differential transmitter rotor to introduce coefficients. An example formula might be as follows:

$$\theta_O = \theta 1 \pm K \theta 2$$

The accuracy of a synchro summing system may be increased by using a two-speed synchro transmission system, as described in chapter 8 of this manual.

MULTIPLICATION

Multiplication is one of the mathematical operations which must be performed in a computer. It may be performed electronically by transistor amplifiers, electron tube amplifiers, or by magnetic amplifiers, electromechanically by potentiometers, and mechanically by devices called multipliers.

Electronic Methods

Every linear amplifier is a multiplier. The d-c amplifier previously discussed had a voltage gain of 100. Now, a high gain operational amplifier with a gain of 25,000 will be discussed. The complete high gain operational amplifier is shown in figure 13-10. The maximum allowable output voltage is ±5 volts. Since the circuit voltage gain is 25,000, the input signal should not exceed ±0.0002 volt (0.2 millivolt).

When the amplifier is used as an operational amplifier, the following restrictions are observed:

1. The gain with feedback should never produce an output greater than 5 volts.
2. The input resistor should be small compared with the input resistance of the operational amplifier. This limits the value to about 5K (one-tenth of the input resistance). The feedback resistor can be any desired value.
3. The input resistance of the following stage must be 1500 ohms or more.

The input stage (fig. 13-10) is composed of transistor Q1 and is a grounded collector amplifier. The voltage divider in the collector circuit provides a small negative voltage for the collector of the transistor. This voltage, approximately -0.8 volt, allows the output of the stage to assume small negative values. The input voltage varies from zero to plus or minus 0.0002 volt. As a result, the output voltage of the first stage is in this range.

The second stage (fig. 13-10) consists of transistor Q2, which is a common emitter amplifier. The 33-ohm resistor in the emitter circuit develops the bias voltage for the stage; that is, the voltage divider network causes the emitter junction to be positive with respect to the base. This results in the flow of a small bias current. Also, the 33-ohm resistor causes a negative feedback to occur in the second stage. Although this feedback reduces stage gain, it also provides wide frequency response and reduces noise, drift, and other undesirable effects.

Transistors Q3 and Q4 (fig. 13-10) form the third stage and the output stage and both are

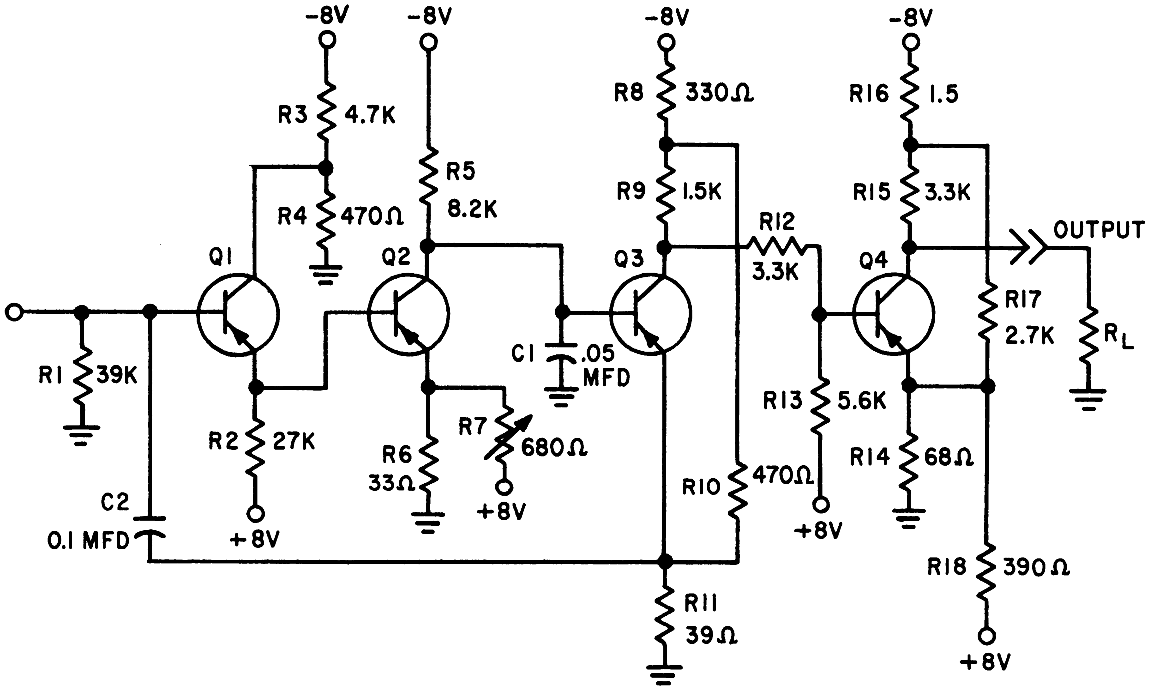

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Figure 13-10.—A high gain operational amplifier.

high gain, common emitter amplifiers. Emitter resistors are used to provide self-bias. Positive feedback is used in these stages to offset the negative feedback introduced by the emitter resistors. The positive feedback is obtained by feeding a portion of the voltage developed across the collector resistors to the emitter. The emitter of the output stage also receives a bias voltage as a result of a series resistor connected to the positive voltage supply.

A block diagram of the high gain operational amplifier is shown in figure 13-11. This block diagram is displayed so that the feedback paths can be more readily seen. Note that a single capacitor C1 is used for phase shift correction. In addition, a special positive feedback path is provided for the higher frequency components of the input signal. Note also that the output of the third stage is in phase with the input because the input stage does not invert the signal.

External feedback resistors are also shown. The gain, with feedback, can be varied from 1 (input resistor of 4.7K and feedback resistance of 4.7K) to 10 (input resistor of 4.7K and feedback resistance of 47K). Higher gains are obtained by using higher values of feedback resistance. In most analog computer applications, however, a gain of 10 is sufficient. Feedback in amplifiers is discussed in detail in Basic Electronics.

Electron tube amplifiers are also capable of solving multiplication problems involving two variables as represented by the equation

$$e_o = kxy$$

Figure 13-12 illustrates a typical triode multiplication circuit. One variable input is applied as grid bias (preferably a d-c voltage) which establishes the gain of the stage. The other variable input is applied to the grid of the tube.

The output is a proportional quantity equal to the grid signal modified by the gain which is proportional to the variable bias voltage. This method is limited in scope and has limited accuracy due to variations in tube characteristics, contact potential, plate and filament supply changes, etc.

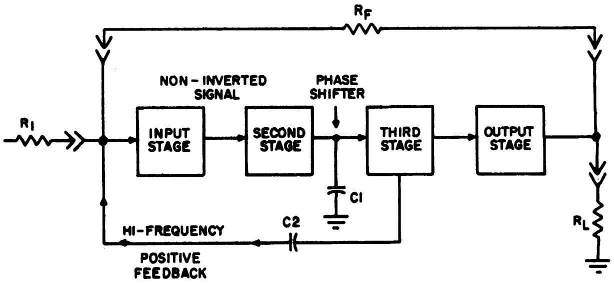

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Figure 13-11.—Block diagram of a high gain operational amplifier.

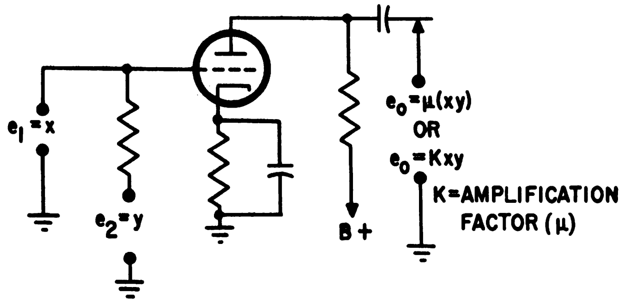

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Figure 13-12.—Variable gain tube as a multiplier.

An improved multiplying circuit is shown in (A) of figure 13-13. Its operation is similar to the circuit shown in figure 13-12 except that it employs the use of two separate grids. The voltage gain of the stage is controlled by the voltage on grid 3 as shown by the curve illustrated in (B) of figure 13-13.

The gain of the amplifier is proportional to the voltage e_3 and may be expressed as follows:

$$A = ke_3$$

If the output voltage e_o is directly proportional to e_1, the input signal, then

$$e_o = Ae_1$$

Substituting for A, we have

$$e_o = ke_1e_3$$

The output is a proportional quantity as indicated by the constant k.

NOTE: It is common in discussions of amplification as related to computers to emphasize

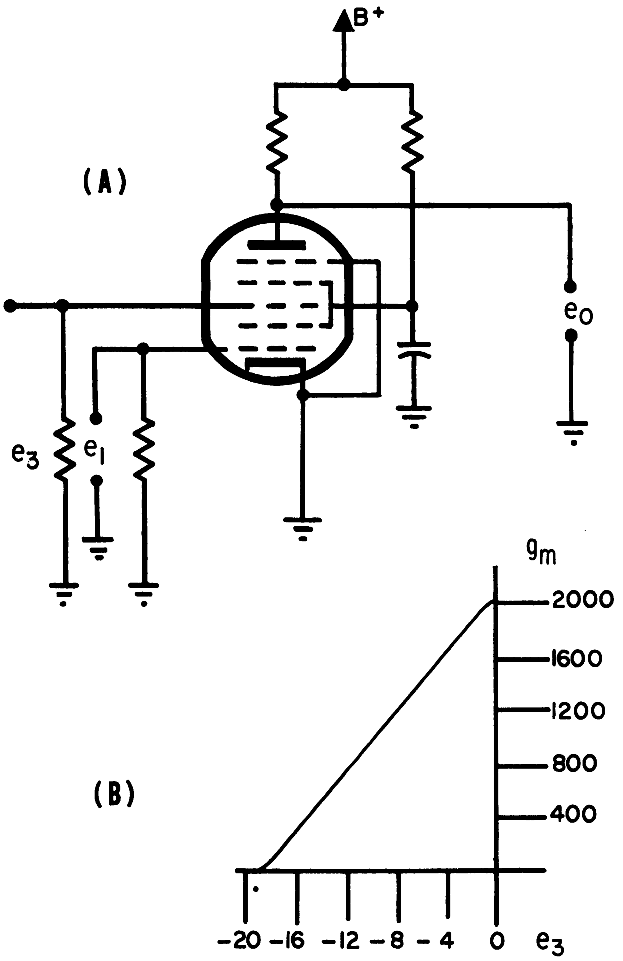

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Figure 13-13.—A multielectrode tube used as a multiplier.

the fact that an odd number of amplifiers inverts the signal. This is interpreted mathematically by use of a negative sign and the symbol A (for amplification factor) and is often written as -A.

Magnetic amplifiers may also be used to multiply one factor by another. The saturable core reactor element in magnetic amplifiers makes the magnetic amplifier easily adapted for multiplying operations. Its amplification can be made proportional to a bias current over a limited range. However, accuracy is limited by variations in magnetic characteristics and winding resistance due to temperature variations.

Electromechanical Methods

Some of the electromechanical devices used for multiplication are potentiometers, synchros, and precision variable autotransformers (usually called by trade name, Variac).

Precision potentiometers are frequently used as multipliers in aviation fire control equipment because they are accurate, rugged, simply constructed, and inexpensive. They are equally well suited for a-c or d-c applications. Figure 13-14 illustrates a typical potentiometer type multiplier circuit.

The voltage occurring between the wiper and one end of the potentiometer is in reality the product of multiplying two quantities:

$$E_o = E_{in}\,\theta$$

One quantity is the voltage impressed across the resistor element, and the other is the position of the wiper. When E_{in} is 100 volts and θ is 100 percent, E_o is equal to 100 volts. If θ is 50 percent of full shaft rotation, E_o is equal to 50 volts. Such close correspondence can be achieved only if the potentiometer is a precision device with linear resistance.

A grounded center tap on the potentiometer winding permits either positive or negative output, depending upon the polarity of the input voltage and the position of the wiper shaft. The potentiometer type multiplier actually multiplies a quantity by a factor of less than one. This presents no problem as the scale factor may be adjusted to give the desired output.

Autotransformer multiplication is identical with potentiometer multiplication except that

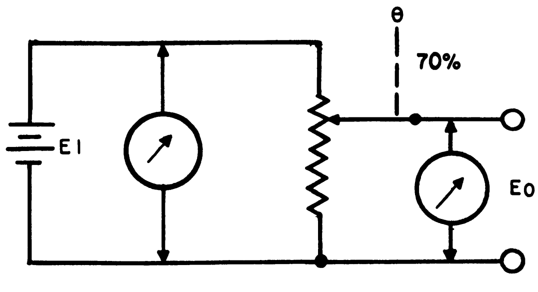

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Figure 13-14.—Potentiometer type multiplier circuit.

the input voltage must be a.c. The input impedance of an autotransformer is high, and its regulation under load variations is very good due to the low d-c resistance of the winding.

The low output impedance of the variable autotransformer permits it to be connected directly to other transformers, potentiometers, or inductive resolvers, without intervening isolation amplifiers.

DIVISION

Instrumentation of division problems in an explicit form is generally difficult to perform. However, division can be accomplished by taking the reciprocal of the divisor and multiplying it by the dividend. This allows the use of less complex multiplication devices, a method normally found in aviation fire control equipments.

Electronic Dividers

Electronic division can be performed by inserting a vacuum tube in place of the variable resistor in a rheostat divider network. The plate resistance of the tube is varied by the voltage applied to the control grid. Figure 13-15 illustrates the circuit of an electronic divider.

The cathode resistor performs the same function as R2 in figure 13-16. As in other electronic circuits, the circuit must be operated within limits determined by its components.

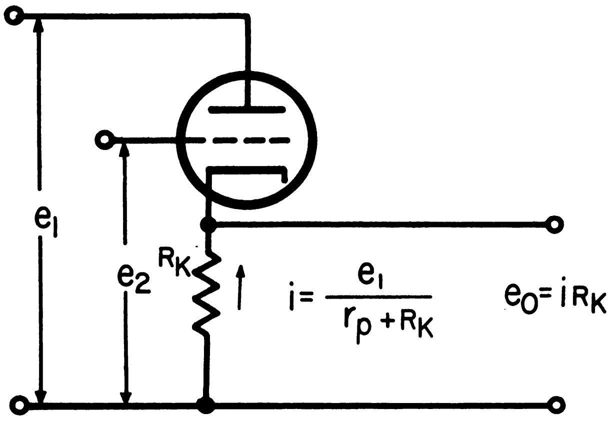

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Figure 13-15.—Electronic divider circuit.

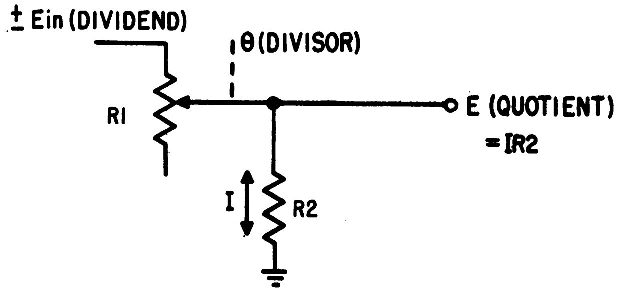

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Figure 13-16.—Rheostat divider network.

Electromechanical Dividers

A rheostat, or a potentiometer connected as a rheostat in a voltage divider circuit, provides a means of dividing a voltage by a shaft position. The voltage divider is an extremely simple method of dividing. The input voltage is applied to one end of the rheostat, and the second input is the shaft position of the rheostat. Figure 13-16 illustrates the operation of a divider network.

Since the shaft position of the movable contact controls the series resistance, current is a quotient of voltage divided by the circuit resistance. The quotient can be obtained as a voltage across the fixed resistor R2, in series with the rheostat. As in any analog system of division, the divisor cannot go to zero since the quotient would then become infinity. R2 limits the current, and its value establishes the range of the divisor.

A voltage E_{in} is made proportional to one input and the resistance R1 + R2 is proportional to the second input.

The current

$$I = \frac{E_{in}}{R1 + R2}$$

The output voltage

$$E_o = \frac{E_{in}}{R1 + R2} \times R2$$

or

$$\frac{E_o}{R2} = \frac{E_{in}}{R1 + R2}$$

Substituting K for the constant value of R2, and θ for the variable R1:

$$\frac{E_o}{K} = \frac{E_{in}}{\theta + K}$$

The term K affects E_o only as a scale factor change. It affects θ only as a shift in value. Consider as an example the equation for determining angular velocity.

$$\omega = \frac{S}{D} \text{ radians per second}$$

where S is linear velocity in feet per second and D is the slant range with limits from 600 to 6,000 feet.

The value of R2 represents the minimum range of 600 feet and R1 + R2 represents 6,000 feet.

$$\frac{R2}{R1 + R2} + \frac{600}{6,000} \text{ or } R1 = 9R2$$

A value for R2 is selected which will produce reasonable current limits over the range of E_{in}. If E_{in} has a range from +100 to -100 volts and the maximum current which may be drawn is 10 ma, R2 becomes 10,000 ohms. R1 will then vary from 0 to 90,000 ohms as D goes from 600 to 6,000 feet. E_o at maximum speed and minimum range will be as follows:

$$\frac{100 \times 10,000}{10,000} = 100 \text{ volts}$$

When D = 6,000 feet, maximum speed will produce an angular velocity output represented by an output voltage E_o of:

$$\frac{100 \times 10,000}{90,000 + 10,000} = 10 \text{ volts}$$

Since range cannot have a negative value, this method is only suitable when the divisor has the same polarity at all times.

Servomechanisms are often used for implicit division in computers. Division is usually represented by the equation

$$x = \frac{y}{z}$$

However, in order to utilize a servomechanism, the equation is rearranged as follows:

$$y - xz = 0$$

The instrumentation of the equation is shown in figure 13-17.

The system has two electrical inputs, the amplitude and polarity of which are determined in other units. The voltage y is fed directly to the error detector while the voltage z is multiplied by the shaft position x, with the product xz being fed to the error detector for comparison with the input y. As in any servosystem,

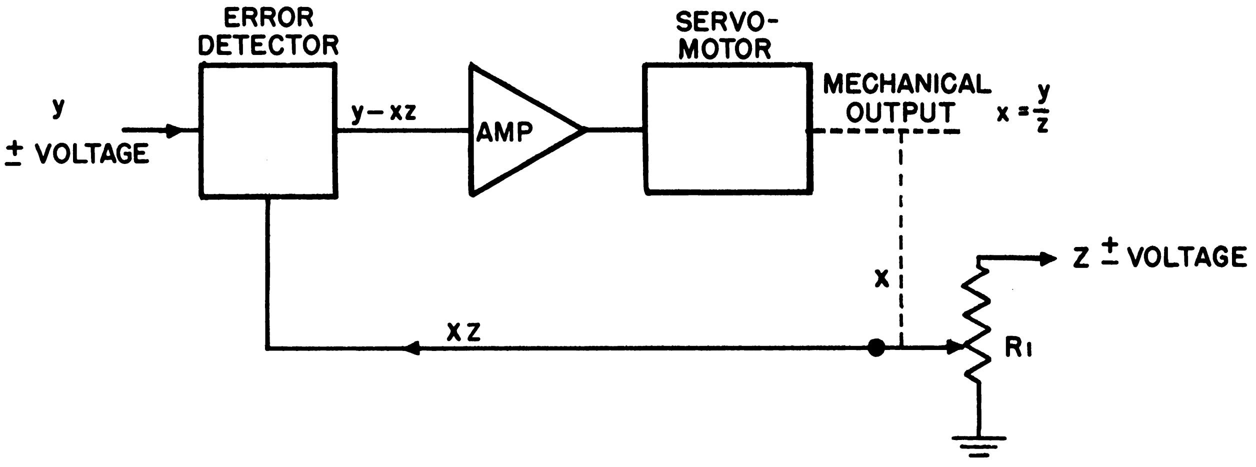

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Figure 13-17.—Division with a servomechanism.

the error voltage drives the servomotor in the direction that will cancel the error voltage, giving a zero output.

NONLINEAR FUNCTIONS

Under this heading, instrumentation of various mathematical operations, such as raising a term to a power or extracting a root of a term, is discussed. It also includes the generation of trigonometric functions.

Most of these operations can be performed by mechanical, electromechanical, and electronic devices. However, one type of device may be more adaptable to a particular operation than another when considering the requirements of an aviation fire control computer. Nonlinear mathematical operations may also be performed by special applications of linear devices previously discussed. For example, a term may be raised to the second power by simply multiplying it by itself, using some type of linear multiplier.

POWERS AND ROOTS

A variety of methods are used in aviation fire control equipment for solving problems involving powers and roots. The most common method utilizes electromechanical principles.

The solution of the armament control problem requires use of devices capable of raising terms to a power. In most cases, the term is raised to the second power (squared).

There are several electronic circuits capable of performing this operation. Perhaps the simplest of the group is a modified use of the multiplying circuit previously discussed and shown in figure 13-13. By applying the input value to both grids 1 and 3, the output voltage will be proportional to the square of the input.

Another electronic circuit capable of squaring is called the squaring amplifier. It consists of a paraphase amplifier with its outputs driving push-pull triode amplifiers. Its output is also proportional to the square of the input, requiring a change in scale factor.

A common electromechanical method of raising a term to a power is by successive multiplication with potentiometer multipliers. (See fig. 13-14.)

When the equation is $y = kx^2$, ganged potentiometers may be used, provided that x is the common shaft position of the potentiometers. This circuit is illustrated in figure 13-18. The variable x may be raised successively to higher powers by repeating this circuit with additional potentiometers.

The voltage (ex) at the variable tap of R1 is at all times proportional to x. The voltage at the tap of R1 is fed through an isolating circuit to R2. The voltage to R2 is equal to ex. This voltage is again multiplied by x and the output voltage at the variable tap of R2 is equal to x times ex, or ex^2.

Using the values shown in figure 13-18, the squaring process may be explained mathematically as follows:

The fixed voltage e corresponds to the constant k, in the expression $y = kx^2$. Placing the two forms of the equation side by side for comparison,

$$y = kx^2 \qquad e_o = ex^2 = [ex]\ (x)$$

$$y = 100(0.50)^2 \qquad e_o = [(100)(0.50)]\ (0.50)$$

$$y = 25 \qquad e_o = 25$$

The mechanization of these equations in terms of percentage of travel by the potentiometer wipers, can be described as follows: If the control of the potentiometers (x) is calibrated in equal units from 0 to 10, then 5 on the dial would represent 50 percent of total travel and 50 percent of E1 would appear at the wiper of R1. With this 50 volts applied to R2 and the wiper of R2 at 50 percent of its travel, 25 percent (50 percent x 50 percent) of E1 will appear at the wiper of R2. If the output meter is calibrated to read 0=100 volts, then in this case it will read 25. In effect, we have squared the number 5.

The power to which a quantity can be raised is limited by the practical limits of voltage available to R1.

The root of a term may be extracted by either electromechanical or electronic devices. In fact, any multiplying or integrating device capable of raising a term to a power and also capable of producing inverse functions can be used to produce roots. However, the extracting of roots is usually accomplished by electromechanical devices.

An electromechanical device for extracting the root of a term or number is the servomechanism feedback loop which utilizes ganged potentiometers as shown in figure 13-19. The equation $y = \sqrt[n]{x}$ may be written as $x = y^n = 0$ by raising both sides to the nth power and

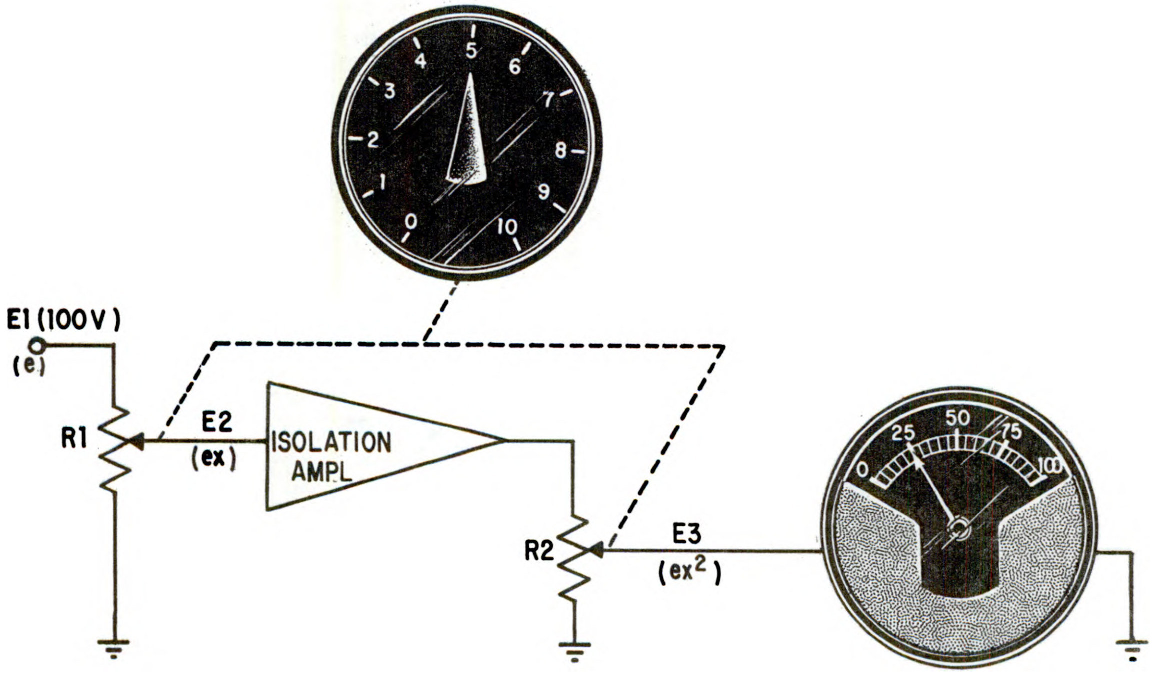

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Figure 13-18.—Powers by successive multiplication.

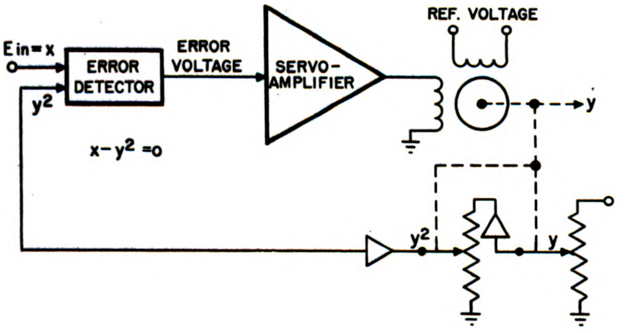

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Figure 13-19.—Square root servomechanism.

transposing the y term. Now the equation is in required form for servomechanism instrumentation.

Square root is solved by multiplying the output quantity by itself and using this value as the feedback term. The output of the square root device is in the form of a shaft position, y.

TRIGONOMETRIC FUNCTIONS

Trigonometric processes can be carried out with inductive resolvers, potentiometers, or all-mechanical devices. Electronic networks consisting of R and C are also sometimes used to perform some trigonometric functions, such as vector addition.

The trigonometric functions most often used in fire control equipment are sines and cosines of angles. However, the four remaining functions may be computed based on the sine and cosine. Those who are not familiar with trigonometry should study Mathematics, Vol. 2.

Electromechanical Devices

The inductive resolver is one of the most common a-c electromechanical devices used to generate trigonometric functions. It is basically a right triangle solver, using windings to represent the sides and magnetic flux to represent the hypotenuse. The shaft rotation corresponds to one of the angles of the right triangle that is to be solved.

The construction is very similar to that of a synchro, except that both the rotor and stator have two windings oriented 90° from each other as shown in figure 13-20. Their primary use is to resolve a voltage into two components at right angles or to combine two component voltages into their vector sum.

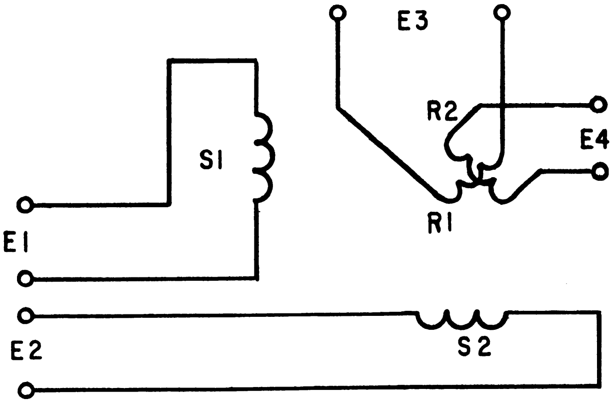

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Figure 13-20.—Inductive resolver diagram.

When a rotor winding is parallel to one stator winding, the device acts as a one-to-one transformer. As the rotor winding is rotated, the voltage induced depends on the sine of the angle of rotation times the applied voltage.

$$E_o = (E_{in}) (\sin \theta)$$

Figure 13-21 illustrates the action of the inductive resolver for three positions.

If the second rotor winding, as shown in figure 13-22, is at right angles to the first winding, its output will correspond to the cosine of the rotation angle, since

$$\cos \theta = \sin (\theta + 90°)$$

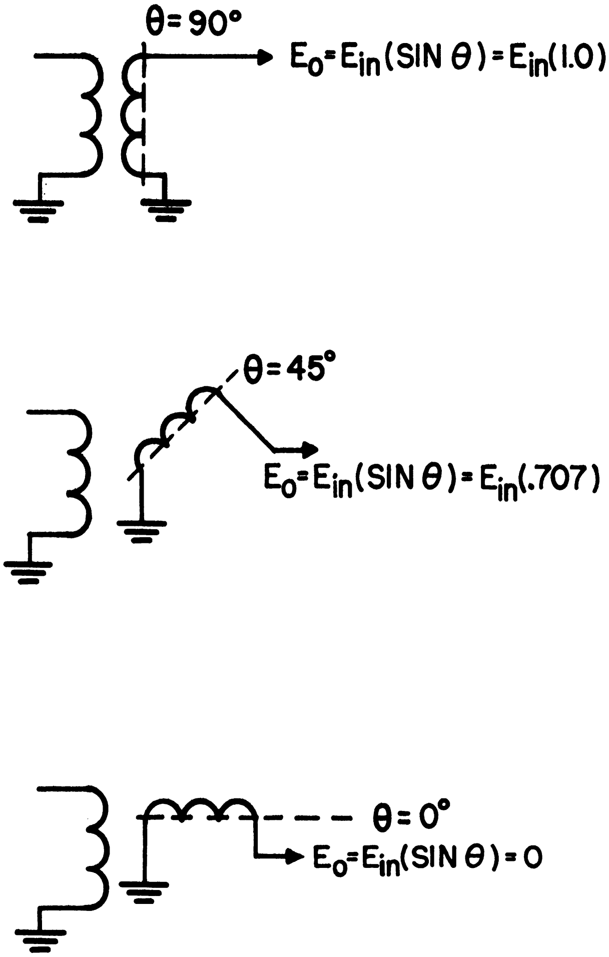

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Figure 13-21.—Inductive resolver action.

Resolvers are low-impedance devices. Isolation or booster amplifiers are generally used as driving circuits if the inductive resolver input signal originates in a high-impedance source, such as a potentiometer. Isolation amplifiers have a low output impedance and can correct for any undesirable phase shift developed in the resolver. Since inductive resolvers operate only with a-c voltages, they cannot be used in d-c analog computers.

Some operations require that the computer be capable of transforming data from a polar to a rectangular coordinate system. If the position of a point or object is defined by a vector, the polar dimensions of the vector may be converted to rectangular coordinates. The vector quantity, distance r and angle θ, may be resolved into horizontal and vertical distances, x and y respectively, with a 2-phase inductive resolver. By feeding a voltage representing the distance r into the stator winding and rotating the rotor shaft through an angle corresponding to θ, voltages representing x and y are produced at the rotor windings as shown in figure 13-23.

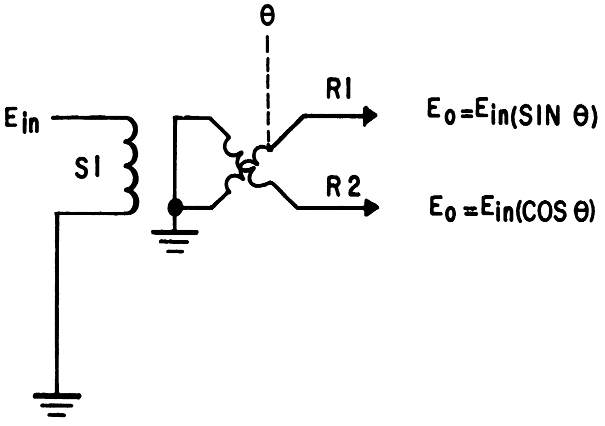

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Figure 13-22.—Inductive resolver with 2-phase winding.

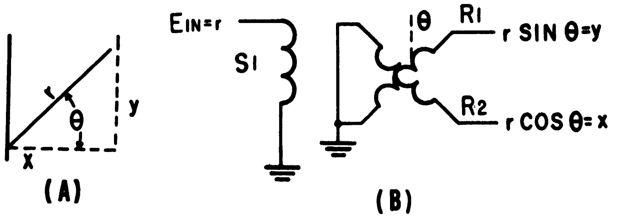

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Figure 13-23.—Polar to rectangular transformation.

Sine and cosine potentiometers are special devices for the selection of a voltage that is indicative of either the sine or cosine of an angle. Output voltages proportional to the product of the input voltage and either the sine or cosine of the angle through which the shaft is rotated can be obtained from the specially designed potentiometers.

LOGARITHMS

The application of logarithms to perform multiplication and division was briefly discussed earlier in this chapter. A study of logarithmic processes in Mathematics, Vol. 2, will indicate that logarithms are also useful in raising a term to a power or extracting a root of a term with the use of logarithms. In this section we are primarily concerned with computing devices for obtaining the logarithm of a term.

Diodes and contact rectifiers under some conditions have nearly exponential variation of current with voltage, or logarithmic variation of voltage with current. However, the operating limits of a single diode are surpassed by the requirements of most armament control computers. This limitation necessitates the use of circuits such as the one shown in figure 13-24 to produce logarithmic functions.

The purpose of this circuit is to produce an output voltage that is proportional to the logarithm of the input current. Referring to figure 13-24, it should be noted that R2, R4, and R6 form a voltage divider network. The cathode of each rectifier is connected through a resistor to some point on the voltage divider. This effectively acts as bias, causing each rectifier to be cut off until its plate reaches a potential higher than its cathode.

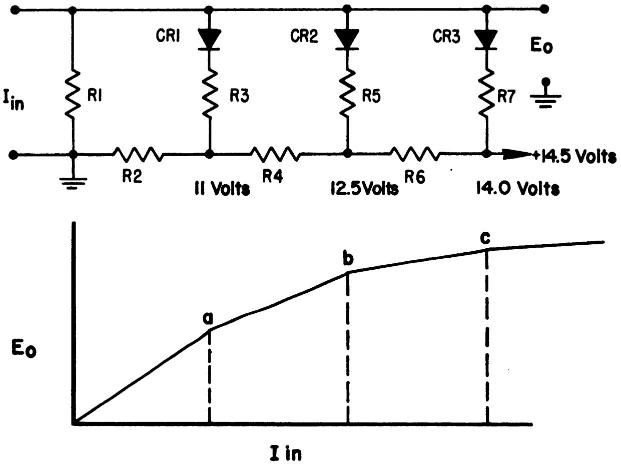

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Figure 13-24.—Typical logarithmic shaping network.

As the input current is applied, current flow will be up through R1 producing an output voltage proportional to the current (E = IR). As the current, hence the voltage drop across R1, becomes great enough, the positive voltage at the top of R1 will become great enough to bring CR1 into conduction. As soon as CR1 conducts, it effectively places R3 in parallel with R1, lowering the total resistance and producing less voltage drop for a given increase in input current. This accounts for the bend in the curve at point a. The circuit response curve illustrates how the slope is successively reduced as additional rectifiers come into conduction. It should also be noted that an increased number of rectifiers could result in a more perfect curve. However, the circuit shown provides an output well within the tolerances required for fire control computers.

There are several means available of obtaining the antilogarithm of a quantity. This may be done either by employing an exponential characteristic directly or by the use of a feedback loop. Implicit methods may also be used, such as taking the derivative of the term in order to eliminate the logarithm in the equation.

CALCULUS

Calculus is a branch of mathematics that deals with the rate of change of a function and with the inverse process which is the determination of a function from its rate of change. The process of determining the rate of change of one variable with respect to another is called differentiation or differential calculus. The process of determining the sum of many minute quantities is referred to as integration or integral calculus.

DIFFERENTIATION

Before going into the actual process of differentiation, the terminology used is discussed briefly. Consider the equation x = f(y). It should be read as: x equals a function of y. If the derivative of x is taken with respect to y, then it would be written as:

$$\frac{dx}{dy} = d\,\frac{[f(y)]}{dy}$$

which, in notation form, is

$$\frac{dx}{dy} = f'(y)$$

$$dx = f'(y)dy$$

Note that the prime indicates the first derivative of the function. When the derivative is a time derivative, it is common practice to shorten the symbol even more, especially for diagrams. For example, dx/dt (where t represents time) is often shortened to $\dot{x}$ (note the dot over the x).

Although y represents any variable, we are generally interested in the derivative with respect to time. The derivative of a quantity with respect to time can be thought of as the time rate of change of that quantity. For motion along a straight line, for example, the derivative of the distance traversed with respect to time is the velocity or the time rate of change of distance. Similarly, the derivative of a voltage with respect to time is the time rate of change of that voltage. Figure 13-25 shows a graphical representation of the derivative of a voltage. If a voltage E_{in} is changing at a constant rate as shown in (A) of figure 13-25, then the derivative E_o of that voltage has a constant value as shown in (B).

Electronic Methods

The rate at which an input voltage is changing can be obtained from a simple series-connected resistor and capacitor circuit as shown in (A) of figure 13-26. Notice that the output voltage of this circuit appears across the resistor. With the proper values of R and C to provide a short RC time constant and with a square-wave input

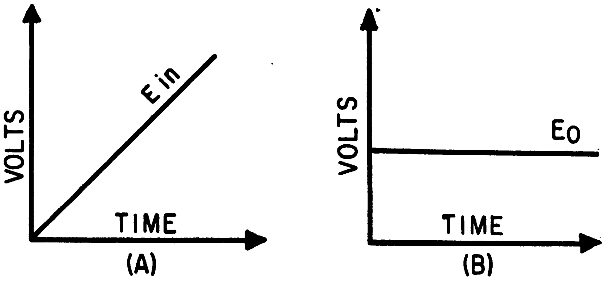

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Figure 13-25.—Graphic representation of the derivative of a voltage.

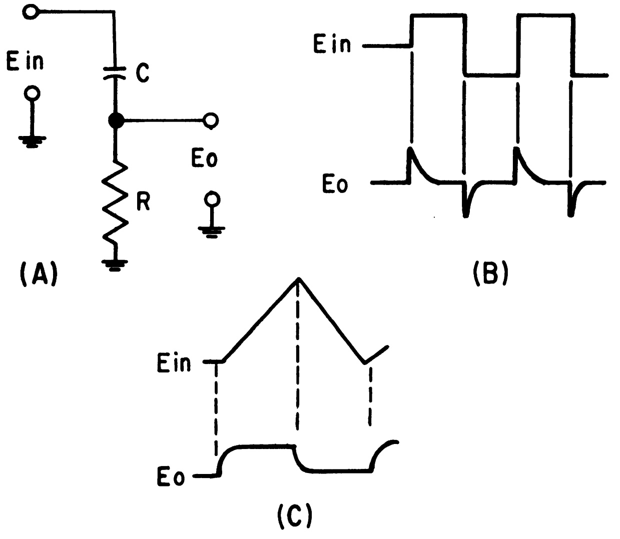

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Figure 13-26.—Simple differentiating circuit.

voltage E_{in}, the output voltage E_o will be that shown in (B) of figure 13-26. When the rate of change of E_{in} is greatest, the value of E_o is greatest; when the rate of change of E_{in} is zero, the output E_o tends toward zero. The derivative of a triangular wave or a sawtooth wave is shown in (C) of figure 13-26. These facts illustrate that the output voltage is approximately equal to the time rate of change (derivative) of the input voltage. For a review of RC differentiating circuits, see Basic Electronics.

The primary disadvantage of the simple differentiating circuit is the time required for the output voltage to become equal to the derivative of the input voltage. Shortening the RC time constant to decrease this time decreases the amplitude of the output voltage.

A feedback amplifier differentiator is shown in figure 13-27. This type of differentiator is superior to the simple differentiator circuit, because its output voltage approximates the derivative of the input voltage in a much shorter time and with greater accuracy. However, the differentiator circuit using a feedback amplifier is limited to use in those situations where introduction of electronic noise is not a serious problem. They act as high-pass filters, and this causes amplification of circuit noise and introduces instability in the amplifier. In a circuit where noise is already a problem, differentiation must be accomplished by setting up an implicit function; this allows indirect differentiation by operating "in reverse" and using integrators.

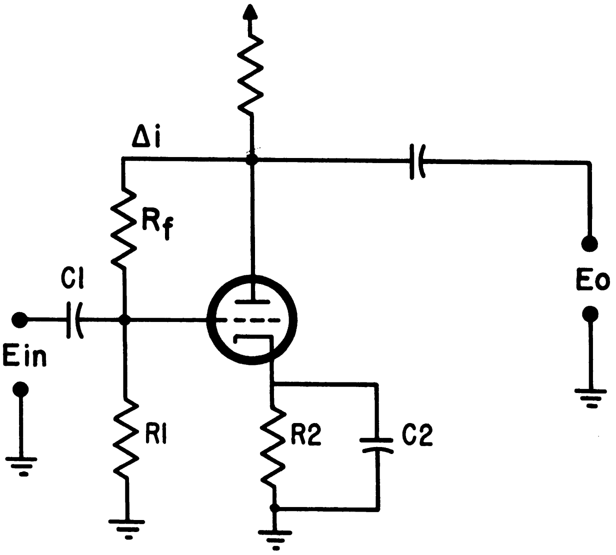

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Figure 13-27.—Differentiating circuit employing a feedback amplifier.

In the following discussion involving the application of a feedback amplifier, it is presupposed that the reader has a thorough understanding of the theory of negative feedback amplifiers. Therefore, anyone not possessing this understanding should study Basic Electronics.

Before discussing the operation of the differentiator amplifier circuit, the following conditions are established:

1. The amplifier must be biased so as to operate near the center of its linear range and not draw any grid current when operating within its specified limits.

2. The grid voltage is near ground potential and changes only a very small amount when the input signal varies. This occurs because the feedback voltage tends to prevent any change in grid voltage.

3. Since the grid voltage remains almost constant, any change in plate voltage due to an input signal appears almost entirely across the feedback resistor, causing a corresponding

change in current through it. Therefore, the output voltage E_o is given by the formula

$$E_o = -\Delta i R_f$$

In this formula, E_o is the change in plate voltage (a-c component) resulting from an input signal applied to the grid, Δi is the change in current flowing through the feedback resistor, and R_f is the feedback resistor.

The formula can be restated in more simple terms, keeping in mind that a differentiator produces an output only when there is a change in the input voltage. The amplitude of the output voltage (a.c.) is equal to the change in feedback current (a-c component) multiplied by the resistance of the feedback resistor. The negative sign serves to emphasize the fact that a polarity inversion is introduced by the amplifier.

Consider the action of the circuit with a constantly changing voltage applied. (See fig. 13-27.) For simplicity of explanation, consider a back-to-back sawtooth that is starting downward from its apex. As the negative-going signal starts downward, electrons from the grid side of C1 start to flow through R_f (electrons are attracted to the higher potential of the plate) causing the grid voltage to drop. This action reduces plate current, causing a rise in plate voltage. A portion of the plate voltage increase is fed back to the grid, causing it to rise in potential. However, since the feedback voltage is only a small portion of the plate signal, the grid cannot come back to its initial voltage. The grid and plate will reach a state of equilibrium almost instantly and remain balanced as long as the current through R_f is constant. With an input voltage which is linear, the discharge current of C1 will remain constant through R_f until the input reverses its direction.

Since the plate is the source of the output, observe its action closely. Remember that the output is only the a-c component of the plate voltage. When the input signal started downward, the plate voltage shot up and leveled off instantaneously and remained at this level until the input signal reversed its direction. This produced a square-wave output that is opposite in polarity to the input. The other half cycle will produce a similar output. Therefore, the output is a voltage waveform indicative of the rate of change of the input voltage. In the fire control computer, this input voltage may represent an input variable such as range, and the output voltage may represent range rate or velocity.

Electromechanical Methods

When the derivative of a voltage is desired, a generator driven by a servomechanism may be used. In this case the servo transforms the voltage to be differentiated into a corresponding shaft position. A generator which is driven by the servo shaft produces an output voltage proportional to the speed of the motor. The generator voltage is a derivative of the rotor displacement with respect to time or a measure of the rate of rotor rotation. (See fig. 13-28.)

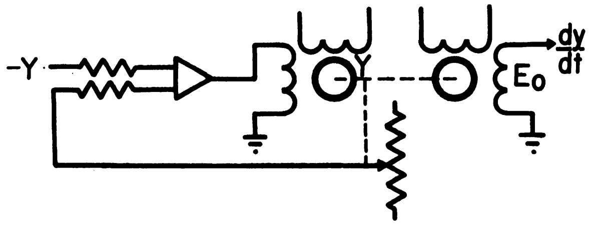

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Figure 13-28.—Electromechanical differentiator.

The derivative range is limited by the response of the servomechanism. A system having moving parts with appreciable inertia cannot respond satisfactorily to a voltage step function, where the slope is infinite.

INTEGRATION

Integration is the process of summing up an infinite number of minute quantities. However, in the solution of the armament control problem, integration is usually the summing of certain quantities in respect to time. For example, taking the integral of velocity between certain limits of time will give the distance traveled.

The process of integration is analogous to determining the area under a curve. In the case of a step function input, the "curve" may be considered as a rectangle having one side variable with time. In figure 13-29 (A), the solid curve Y1 shows the velocity at any time, in this case a constant velocity. The distance traveled is equal to the velocity multiplied by the time; and with proper scale values, the distance is given by the numerical area under this (rectangular) curve; that is, area = height (or velocity) multiplied by length (or time). On the distance-time diagram, the sloping line X1 shows the total distance traveled at any instant of time; and the larger the step input the steeper the slope of the line in the distance-time diagram.

The distance traveled, x, must continue to increase as long as there is a positive value of velocity, y. When x is represented by a voltage, there are limitations on its maximum value due to circuitry to be used.

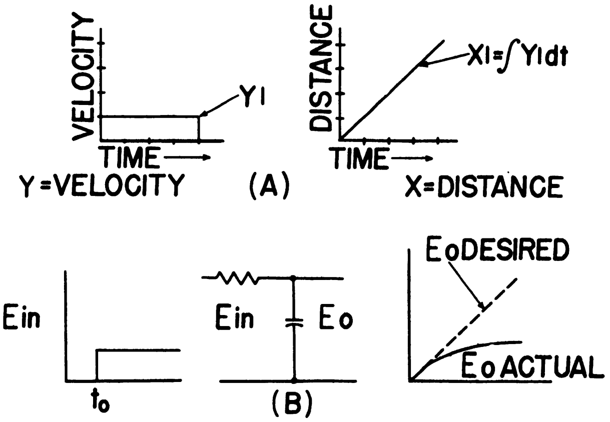

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Figure 13-29.—Integration of area.

The integral of a d-c voltage is a voltage with a constant slope as shown in figure 13-30. There is normally no need of integrating d-c voltages but this effect is identical to the voltage wave for step inputs.

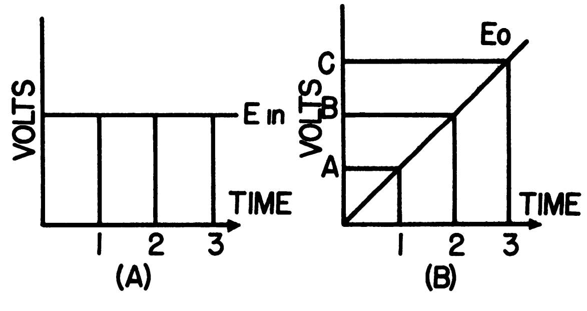

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Figure 13-30.—Graphical representation of integration of a voltage.

A simple integrator is shown in (A) of figure 13-31. Here a square-wave voltage is applied to the input, and the output voltage appears across the capacitor. During the positive portions of the input voltage, the output voltage is the sum of all the positive quantities, which results in an increasing voltage. During the negative portions of the input voltage, the output voltage is the sum of all of the negative quantities in the input, which results in a decreasing voltage. Study the waveforms in (B) of figure 13-31 and compare them with the output of the simple differentiator circuit. The integrator output and the differentiator output combined equal the instantaneous input voltage, except for circuit losses.

For further details concerning simple integrator circuits, review the discussion of this topic in Basic Electronics.

An integrating amplifier circuit utilizing a feedback amplifier is shown in figure 13-32. This circuit is very similar to the differentiating amplifier circuit discussed previously. However, it should be noted that the negative feedback is coupled from plate to grid with a large coupling capacitor. This capacitor, along with the input resistor and load resistor, performs the integration. The amplifier functions only to improve its response and linearity. The input circuit also utilizes an isolation resistor (R1) to allow the grid to be maintained at an almost constant potential when an input signal is applied.

The output is based on the rate of charge, or discharge, of the feedback capacitor. The

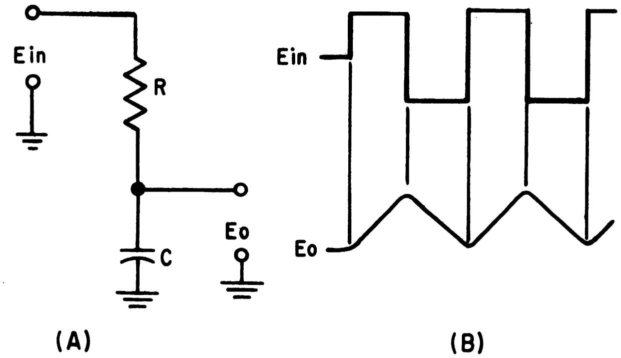

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Figure 13-31.—Simple integrating circuit.

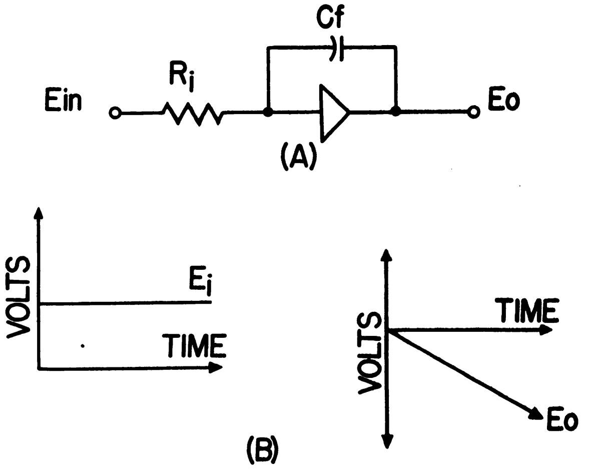

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Figure 13-32.—A common integrating circuit.

amplifier functions to maintain the charge, or discharge, of the integrating capacitor in the linear portion of the RC curve. The net effect is that the capacitor voltage does not oppose the input voltage and the capacitor charging current is a direct function of the input signal voltage.

GROUPED OPERATIONS

Thus far in this chapter computing devices for performing various mathematical operations have been discussed individually. At this point several of the instruments or devices are grouped together for the solution of a problem. It is not intended that such grouping will comprise a workable computer, but rather to show that grouping devices allows the solution of more complex equations which may involve only a small portion of a complete computer. The operations of complete computers in the solution of the fire control problem will be discussed in the ensuing chapters.

PROBLEMS ENCOUNTERED

When various devices are selected to carry out a grouped operation, certain problems are almost certain to develop. Such problems are present even in the grouping of the simplest devices. Here again this information is presented not to help you design a computer, but to aid you in understanding the more complex computers.

Change of Representation

With the connecting of two or more computing devices, the use of two or more methods of representation are frequently required. The output of the first device may not have the same representation as required by the input of the second device. An example might be the multiplication of two voltages by a potentiometer type multiplier. To successfully multiply, one of the voltages would have to be represented by a shaft rotation.

Scale Factor

Another problem that must be considered when grouping two or more devices is that of scale factor. As pointed out previously, a change of scale factor takes place any time the device produces a proportional output. Such devices include those which perform the operations of adding, multiplying, dividing, etc.

Impedance Matching

When the output of one electronic circuit is fed to another, the input impedance of the second circuit or stage may affect the operation of the first. Therefore, it is important that the input impedance of the second circuit be matched to the output impedance of the driving stage. A mismatch may result in an error in the computer, making the complete computer inaccurate. Two devices often used between two computing circuits are the cathode follower and impedance matching transformers. Impedance matching in the use of electrical components, such as resolvers and control transformers, must also be considered.

Speed of Computation

The speed of response of a device is important in grouped operation. Some devices have a shorter response time than others. For example, a device with a minimum speed of computation time, when required to function longer than the minimum time, may lose a considerable percentage of its accuracy. The overall accuracy of a group of devices could be reduced below the desired tolerance due to one device requiring a longer time to function than the rest of the

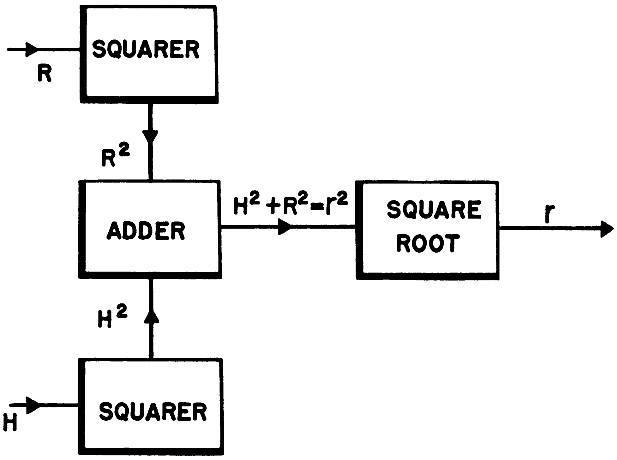

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Figure 13-33.—Block diagram of right triangle solver.

group. The speed of response is an important factor in regard to the stability of computers utilizing feedback.

TYPICAL EQUATION SOLUTION

In the solution of the bombing problem, it is necessary to find the hypotenuse of a right triangle when the length of the two sides is given. Bombing computers normally utilize ground range or horizontal range because ground range rates are more constant than slant range rates. However, to minimize the possibility of error, computed ground range is converted into slant range for comparison with observed radar range. This requires a constant solution from the following equation:

$$r = \sqrt{H^2 + R^2}$$

where

r = slant range
H = altitude
R = ground range

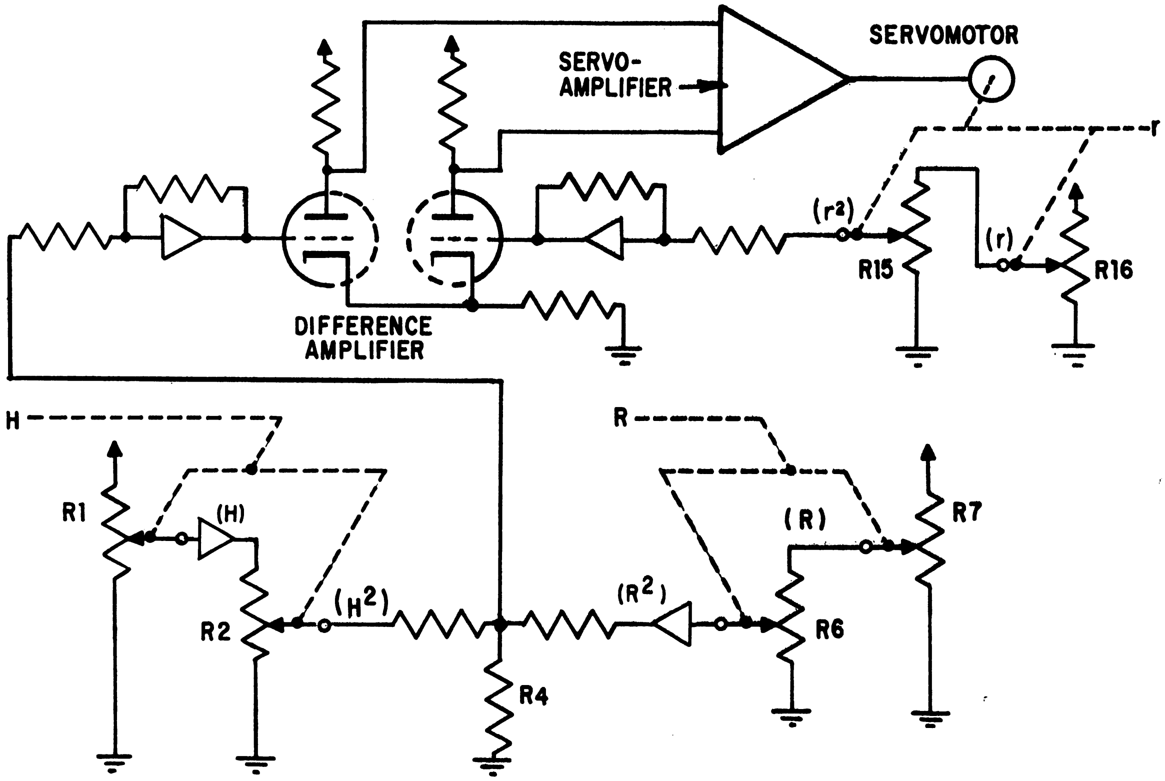

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Figure 13-34.—Schematic diagram of a right triangle solver.

A block diagram of a squaring type triangle solver is shown in figure 13-33. The quantities H and R are squared and summed. The summed quantity ($R^2 + H^2$) is fed to a device that extracts the square root, giving an output equal to r.

A simplified circuit capable of performing the above operation is illustrated in figure 13-34. The quantities H, R, and r are represented by their respective shaft positions. Ganged potentiometers are used for squaring each quantity. A voltage proportional to $H^2 + R^2$ appears across R4, and is fed to a feedback amplifier. Here the signal is amplified and the scale factor is corrected prior to being fed to the difference amplifier.

Potentiometers R15 and R16 are squaring potentiometers with the output being a voltage proportional to r^2. This signal is also amplified and fed to the difference amplifier. If the voltage r^2 is equal to the voltage $H^2 + R^2$, the output from the difference amplifier is zero and the position of the r shaft is indicative of

$$\sqrt{H^2 + R^2}$$

However, if there is a difference in the two inputs, the output signal fed to the servoamplifier will cause the servomotor to rotate in a direction to reduce the difference voltage, thus correcting the output r.

It should be remembered that this example is only one of many possible ways of solving a right triangle. It is included only to show that the devices discussed earlier in this chapter may be grouped for the solution of more complex equations.

There are many applications of the analog type computer in naval aviation. The trend of today's weapons systems is toward computers called hybrids. These computers are a combination of both analog and digital computing devices. This arrangement will probably remain for some time since many of the input and output devices must be analog. Input devices of the analog type are required to receive the data from a radar set, airspeed probe, or a shaft position since this type of data is analog in nature.

One specific example of an electronic type analog computer is included in chapter 15 of this manual.

CHAPTER 14

DIGITAL COMPUTERS

Present and future technicians will be faced with a collection of electronic equipments which use computers as integral portions of the overall system. To understand the operation of the system in general, and the computer portion in particular, it is necessary to have a basic understanding of computer functions, circuitry, terminology, and applications. Basic Electronics, NavPers 10087-C, Digital Computer Basics, NavPers 10088, and Mathematics, Vol. 3, NavPers 10073-A, present a basic coverage of the purpose, operation, and theory of computers, together with some of the terminology peculiar to them. Review and study of these basic coverages will aid in understanding the material covered in this chapter.

INTRODUCTION TO DIGITAL COMPUTERS

In the past few years, the term digital computer has appeared in Navy nomenclature. This term refers to an electromechanical device which is used in applications such as weapons guidance, communications, and tactical data processing. Digital computers accomplish things that were impossible before, and they speed up processes which formerly required considerable time. Although the operations of computers are not new, the techniques of electronics have made possible a computer contained in a small, lightweight package which is adaptable to aircraft systems. Also, prior to the incorporation of electronics in digital computers, the great speed of operation required was impossible with purely mechanical devices.

The technician of today is faced with equipments which have the computer used as an integral part of the overall system. Therefore, the technician must have a basic understanding of computer functions, the circuitry involved, the numbering system used, and computer terminology.

The definition of a computer is: Any device capable of accepting information, applying mathematical operations to that information, and obtaining useful results of these operations. Therefore, a computer must have an input, processing, and output section.

Before any problem can be solved by a computer, the quantities involved must be expressed in terms of common units; that is, digital computation is the process in which digits alone are used to solve the problem.

Basically, the purpose of a digital computer is the same as that of any other computational aid. However, it is more accurate within practical limits of speed. Computers can perform thousands of repetitive computations involving hundreds of thousands of digits without making an error. Further, they can store millions of items of information for future use.

Digital computers also have limitations in that a continuous variable cannot be processed. Simple and explicit instructions (programing) must be provided for each operation that is to be performed. Instructions as to where information is stored, how to use it, what to do with it, and what step is required next are sometimes more complicated than the problems the computer is used to solve. Approximations and rounding off are also problems encountered with computers.

A digital computer performs its calculations by counting and comparing. With this simple capability, it can add, subtract, multiply, divide, and make logical decisions. Therefore, to perform computations with a digital computer, all that is needed is the provision of a method which will enable the machine to count, compare, and transfer a digit from one place to another. Therefore, before a discussion of computer devices, it is necessary to learn the language of the computers.

NUMBERING SYSTEMS

While there are many different numbering systems, this discussion will deal with only two; that is, the base ten (decimal) and base two (binary) systems. The binary system will be compared with the decimal system because all computers utilize the binary system and most readers understand the decimal system. The bistable nature of simple electronic components such as switches (open or closed) and tubes and transistors (conducting or cutoff) makes the binary numbering system quite usable.

In the decimal system there are ten digits used (0 through 9), and in the binary system there are two digits used (0 and 1). The symbols or digits used are repeated as many times as desired or needed. Both systems also use the place value of positional notation concept. This means that a numeral has a specific value by virtue of its position.

An example of place value is shown in the two numbers 230 and 203. The 3 has a different value in each numeral by virtue of its position.

POSITIONAL NOTATION

In the previous example the numeral 230 when stated by the reader to be two hundred thirty, some assumptions are made which must be understood in order to compare the decimal and binary systems.

The first assumption the reader made was that when the number 230 was first looked upon, the number was assumed to be a decimal number. When no base symbol is given, the decimal system is assumed. If the number had been a base four number, it would have been written as $230_{(4)}$ with the 4 indicating the base of the numbering system. Some examples and their numbering base symbols are as follows:

Number	Base
398	ten (decimal)
$342_{(5)}$	five (quinary)
$101_{(2)}$	two (binary)

Therefore, when a number is written in base ten, no base indicator is given. If the number is written in a base other than ten, the base indicator is used.

Another assumption made is that the number 230 is two hundred thirty; that is, the digit 2 indicates hundreds, the digit 3 indicates tens, and the digit 0 indicates units. In base ten, this is true. The digits have specific values according to their position. Place value or positional notation for the number 378924 in the decimal system is as follows:

Place value	10^5	10^4	10^3	10^2	10^1	10^0
	100000	10000	1000	100	10	1
Number	3	7	8	9	2	4

Notice that the place value column on the right is 10^0 or 1. The increasing place values, moving to the left, are indicated by the base (10) raised to one greater power. The second place value column is, then, 10^1, the third is 10^2, etc.

The number 378924, then, is 3(100000) + 7(10000) + 8(1000) + 9(100) + 2(10) + 4(1).

The place value columns for the binary (base two) system follow the same pattern as the base ten system except the base two is used.

For example, the number $10110_{(2)}$ is indicated in the place value chart for base two as follows:

Place value	2^4	2^3	2^2	2^1	2^0
	16	8	4	2	1
Number	1	0	1	1	0

The number $10110_{(2)}$, then, is 1(16) + 0(8) + 1(4) + 1(2) + 0(1) = $22_{(10)}$

Notice that place value in base two has a different value than the same place in base ten.

COUNTING IN BASE TWO AND BASE TEN

In base ten, when counting from 0, the numbers are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9.

The next number to be counted is ten, but there is no single symbol in base ten to indicate the next number. Therefore, a combination of symbols is used by repeating the 0 and indicating a 1 in the tens column. This means one group of tens and no groups of units.

When counting in base two, there are only two digits or symbols; that is, 1 and 0. The same mechanical process is used in base two that was used in base ten. Starting with 0, in base two, the count is 0, 1.

There are no other symbols to indicate the next number so a 1 is written in the next place value column to the left and a 0 is written in the first place value column; that is, 0, 1, $10_{(2)}$.

This last number, then, indicates one group of two and no groups of units. The next number is $11_{(2)}$ which means one group of twos and one group of units. A number such as $1101_{(2)}$ would indicate one group of eights, one group of fours, no group of twos, and one group of units, and in this case is the same as decimal number 13.

Counting comparisons between the decimal and binary systems are made as follows:

Decimal	Binary
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111
16	10000
17	10001

Notice that when counting objects, the decimal 17 and binary 10001 refer to the same object; therefore, decimal 17 must be equivalent to binary 10001.

CONVERSIONS

If the binary number 101 is to be converted to a decimal number, the binary number is written in expanded notation; that is

$$101_{(2)} = 1(4) + 0(2) + 1(1)$$

and the indicated multiplication, by terms, is carried out and yields

$$4 + 0 + 1 = 5$$

The 5 is a base ten number; that is, if objects were counted in a row and stopped with the decimal 5 and then the same objects were counted again in binary, the same object would be indicated with one-zero-one ($101_{(2)}$).

Example: Convert $11101_{(2)}$ to base ten.

Solution: Write $11101_{(2)}$ in expanded notation as

$$1(16) + 1(8) + 1(4) + 0(2) + 1(1)$$

and carry out the multiplication to obtain

$$16 + 8 + 4 + 0 + 1 = 29$$

To convert the decimal number 26 to binary, first intuitively determine the largest place value column contained in the number; that is, in the place value chart

2^5	2^4	2^3	2^2	2^1	2^0
32	16	8	4	2	1

there is one group of 16 or 2^4 in 26. Also, there must be five digits in the representation of 26 in binary because the place value column for 2^4 is the fifth place value column from the right. This is indicated by drawing lines for each digit as follows:

2^4	2^3	2^2	2^1	2^0
-	-	-	-	-

There is one group of 16 in 26; therefore, write

2^4	2^3	2^2	2^1	2^0
1	-	-	-	-

Sixteen is indicated, leaving 26 - 16 to be accounted for, or ten. There is one group of 2^3 in ten so write

2^4	2^3	2^2	2^1	2^0
$\underline{1}$	$\underline{1}$	_	_	_

After accounting for one group of 16 and one group of 8, 2 is left. There are no groups of 2^2 in 2 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	_	_

and then find there is one group of 2^1 in 2 and write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	_

leaving 0. Finally there is no group of 2^0 in 0 so write

2^4	2^3	2^2	2^1	2^0
1	1	0	1	0

Therefore, 26 in decimal is equal to 11010 in binary.

This type conversion is quite complicated in dealing with large numbers. There is a technique which enables us to convert from decimal to binary quite simply by continual division of the decimal number by the base of the binary system, indicating the remainder after each division operation until the quotient is zero. This is shown in the following:

Convert 26 decimal to binary—

$2\,\underline{|26}$
13 remainder is 0

$2\,\underline{|13}$
6 remainder is 1

$2\,\underline{|6}$
3 remainder is 0

$2\,\underline{|3}$
1 remainder is 1

$2\,\underline{|1}$
0 remainder is 1

The remainders are read from the bottom to the top to obtain the binary equivalent of the decimal number; that is,

$$26 = 11010_{(2)}$$

The division process may be combined as follows:

Convert 38 to binary—

$2\,\underline{|38}$	
$2\,\underline{|19}$	0
$2\,\underline{|9}$	1
$2\,\underline{|4}$	1
$2\,\underline{|2}$	0
$2\,\underline{|1}$	0
0	1

and the binary equivalent of 38 is $100110_{(2)}$.

BINARY ARITHMETIC

Familiarity with the basic arithmetic operations in the binary system is needed in order to enhance the understanding of computers; therefore, a comparison between the decimal and binary systems will be discussed.

Addition

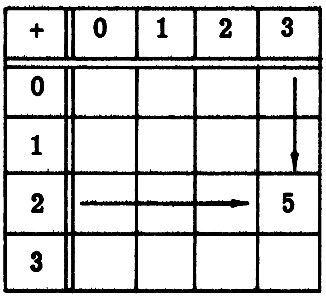
When counting in the decimal system, a limit is reached where the next number cannot be indicated in a single column; that is, when counting from 0 to 9.

At this point a "carry" is made; that is, the first digit (0) is repeated and a 1 is indicated in the tens column. This means one group of tens and no groups of units, and is indicated by 10.

The ADDITION facts of the DECIMAL system are shown in the truth table below:

+	0	1	2	3	...
0	0	1	2	3	...
1	1	2	3	4	...
2	2	3	4	5	...
3	⋮	⋮	⋮	⋮	

For example:



means

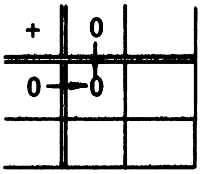
$$2 + 3 = 5$$

Binary addition is similar to decimal addition, except in binary only two digits, 0 and 1, are available. The mechanical procedure is the same.

The ADDITION facts of the BINARY system are as follows:

+	0	1
0	0	1
1	1	10

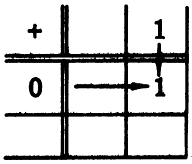
That is,



means

$$0 + 0 = 0$$

and



means

$$0 + 1 = 1$$

or

$$1 + 0 = 1$$

and

+	0	
1	1	

means

$$1 + 0 = 1$$

or

$$0 + 1 = 1$$

and

+		1
1		10

means

$$1 + 1 = 10$$

This means that

$$\begin{aligned} 0 + 0 &= 0 \\ 0 + 1 &= 1 \\ 1 + 0 &= 1 \\ 1 + 1 &= 10 \end{aligned}$$

When adding numbers in base ten, the following mechanical procedure is followed:

Add 172 and 32

$$\begin{array}{rl} 172 & \\ \underline{+\ \ 32} & \\ 104 & \text{partial sum} \\ \underline{+\,100} & \text{carry overs} \\ 204 & \text{final sum} \end{array}$$

When adding two binary numbers, the process is

$$\begin{array}{rl} 0101 & \\ \underline{+\,0111} & \\ 0010 & \text{partial sum} \\ \underline{+\,1010} & \text{carry overs} \\ 1000 & \text{partial sum} \\ \underline{+\,0100} & \text{carry overs} \\ 1100 & \text{final sum} \end{array}$$

The previous addition may be stated as follows:

Starting from the right column, one plus one equals 0 and 1 carry. The carry plus zero plus one equals zero and one carry. The carry plus one plus one equals one and one carry. The carry plus zero plus zero equals one.

Computer Addition

The computer technique of addition utilizes the process of half add, carry, and final sum. Half add means to add two digits and neglect the carry. The carry is written below the half add sum and then added to this half add sum. An example in decimal is as follows:

Add 3562 and 2149

$$\begin{array}{rl} 3562 & \\ +\,2149 & \\ \hline 5601 & \text{half add} \\ +\,0110 & \text{carry overs} \\ \hline 5711 & \text{final sum} \end{array}$$

If other carry overs are required, they are handled as follows:

Add 4965 and 5247

$$\begin{array}{rl} 4965 & \\ +\,5247 & \\ \hline 9102 & \text{half add} \\ +\,1110 & \text{carry overs} \\ \hline 0212 & \text{half add} \\ +\,10000 & \text{carry overs} \\ \hline 10212 & \text{final sum} \end{array}$$

The computer technique is used in binary as it is used in decimal.

Example: Add the binary numbers 11101 and 1101.

$$\begin{array}{lrl} \text{Solution:} & 11101 & \\ & +\;\;1101 & \\ \hline & 10000 & \text{half add} \\ & +\,11010 & \text{carry overs} \\ \hline & 01010 & \text{half add} \\ & +\,100000 & \text{carry overs} \\ \hline & 101010 & \text{final sum} \end{array}$$

Example: Add the binary numbers 1101 and 110.

$$\begin{array}{lrl} \text{Solution:} & 1101 & \\ & +\;\;110 & \\ \hline & 1011 & \text{half add} \\ & +\,1000 & \text{carry over} \\ \hline & 0011 & \text{half add} \\ & +\,10000 & \text{carry over} \\ \hline & 10011 & \text{final sum} \end{array}$$

Subtraction

Both the direct and complement methods of subtraction are discussed. The methods are also compared in the decimal and binary systems.

DIRECT SUBTRACTION.—In the decimal system, when subtractions are made, the terms to be subtracted are named as follows:

$$\begin{array}{rl} 7 & \text{minuend} \\ -\,2 & \text{subtrahend} \\ \hline 5 & \text{difference} \end{array}$$

In cases where the subtrahend, in a particular column, is greater than the minuend, a borrow must be made; that is, a digit must be moved from a higher place value column to a lower place value column. An example is

$$\begin{array}{r} 76 \\ -\,39 \\ \hline \end{array}$$

where 9 is to be subtracted from 6.

In this case one group of tens must be borrowed from the 7 group of tens. This is shown by

$$\begin{array}{r} 76 \\ -\,39 \\ \hline \end{array}$$

is

$$\begin{array}{rr} & 10 \\ 6 & 6 \\ -\,3 & 9 \\ \hline \end{array}$$

and 9 from 16 is 7. Therefore,

$$\begin{array}{rr} 6 & 16 \\ -\,3 & 9 \\ \hline \multicolumn{2}{c}{37} \end{array}$$

This concept may be applied to as many columns as necessary. For example, in the problem

$$\begin{array}{r} 9326 \\ -\,7438 \\ \hline \end{array}$$

one group of tens is borrowed from the two groups to give

$$\begin{array}{rr} & 10 \\ 931 & 6 \\ -\,743 & 8 \\ \hline & 8 \end{array}$$

then one group of hundreds is borrowed from the three groups to give

$$\begin{array}{rrr} & 10 & 10 \\ 92 & 1 & 6 \\ -\,74 & 3 & 8 \\ \hline & 8 & 8 \end{array}$$

The next step is

$$\begin{array}{rrrr} & 10 & 10 & 10 \\ 8 & 2 & 1 & 6 \\ -\,7 & 4 & 3 & 8 \\ \hline & 8 & 8 & 8 \end{array}$$

and finally

$$\begin{array}{rrrr} & 10 & 10 & 10 \\ 8 & 2 & 1 & 6 \\ -\,7 & 4 & 3 & 8 \\ \hline 1 & 8 & 8 & 8 \end{array}$$

The subtraction problem difference may be verified by adding the difference to the subtrahend to give the minuend. This shown by

$$\begin{array}{r} 1888 \\ +\,7438 \\ \hline 9326 \end{array}$$

Binary subtraction problems are solved in the same manner as decimal subtraction problems except base two is used. One fact may cause problems; that is, when 1 is subtracted from 0, the difference is 1 if a borrow of 1 is made. An example of this is shown by the following:

$$\begin{array}{r} 10 \\ -\,1 \\ \hline \end{array}$$

A borrow of 1 is made, to give

$$\begin{array}{rr} & 10 \\ 0 & 0 \\ - & 1 \\ \hline \end{array}$$

10 (which must be read as "one-zero," and not as "ten") in base two is really 2 in decimal, and 1 from 2 is 1. Therefore,

$$\begin{array}{rr} & 10 \\ 0 & 0 \\ - & 1 \\ \hline & 1 \end{array}$$

When no 1 is available in the next higher place value column, a higher place value column must be used. This is shown in the following example of binary subtraction:

$$\begin{array}{r} 100 \\ -\,1 \\ \hline \end{array}$$

A borrow from the 2^2 column is made, giving 10 in the 2^1 column.

$$\begin{array}{rrr} & 10 & \\ 0 & 0 & 0 \\ - & & 1 \\ \hline \end{array}$$

Then, a borrow of 1 is made from the 10 in the 2^1 column, leaving 1 in this column and giving a 10 in the 2^0 column, and 10 minus 1 is 1,

$$\begin{array}{rrr} & & 10 \\ 0 & 1 & 0 \\ - & & 1 \\ \hline \end{array}$$

Therefore,

$$\begin{array}{rrrl} & & 10 & \\ 0 & 1 & 0 & \text{minuend} \\ - & & 1 & \text{subtrahend} \\ \hline 0 & 1 & 1 & \text{difference} \end{array}$$

Verification of this difference is made by adding the subtrahend to the difference to yield the minuend.

$$\begin{array}{r} 011 \\ +\,1 \\ \hline 100 \end{array}$$

SUBTRACTION BY COMPLEMENTS (BASE TEN).—Digital computers are generally unable to perform subtraction in the manner previously discussed because the process of borrowing involves operations which are impractical to incorporate into a machine. The process which involves complements is used in digital computers. By complement, it is meant the number or quantity required to fill or complete something. The complement of a number is therefore, another number which completes the original number with respect to a known reference.

For example, the nines complement of a number is that number when added to the original number that will yield all nines in the place value columns used. An example of this is as follows.

What is the nines complement of 32?

What number, when added to 32, will produce 99?

Intuitively, it can be seen that the number is

$$99 - 32$$

or

$$67$$

If one is now added to the nines complement, the tens complement results; that is,

$$67 + 1 = 68$$

and 68 is the tens complement of 32. Notice that if 68 is added to 32, the sum is 100. Therefore, the tens complement of a number is defined as that number which, when added to the original number, yields a 1 in the next higher place value column and zeros in all other columns. The tens complement of 78 is

$$100 - 78 = 22$$

Notice that the tens complement is in reference to a power of ten one place value higher than the highest place value of the original number.

Number	Tens complement	Reference
7	3	10^1
21	79	10^2
309	691	10^3

Rather than subtract the subtrahend from the minuend, the tens complement of the subtrahend (found with reference to the power of ten one place value higher than either the subtrahend or minuend) may be added to the minuend and then decrease this sum by the reference power of ten used to obtain the difference. A step-by-step process is shown to explain the preceding statement.

Example: Subtract 26 from 49

Solution: Write

$$\begin{array}{r} 49 \\ -\ 26 \\ \hline \end{array}$$

then find the tens complement of 26 which is

$$100 - 26 = 74$$

This may be rearranged as follows:

$$100 - 74 = 26$$

Now, instead of writing

$$49 - 26$$

write

$$\begin{aligned} & 49 - (100 - 74) \\ = {} & 49 - 100 + 74 \\ = {} & 49 + 74 - 100 \\ = {} & 23 \end{aligned}$$

This indicates that the minuend (49) plus the tens complement of 26 (that is, 74) are added, then the reference power of ten used (100) is subtracted to give the difference which is 23. Notice that

$$\begin{aligned} & 49 - 26 \\ = {} & 49 + 74 - 100 \\ = {} & 123 - 100 \\ = {} & 23 \end{aligned}$$

the digit (1) found in the place value column higher than the highest place value column of the subtrahend had only to be dropped. Generally, this digit (1) which is developed indicates the difference (23) is a positive value.

Example: Subtract 36 from 429

Solution: Write

429 minuend
- 36 subtrahend

then

429 minuend
+ 964 tens complement of subtrahend
1 ⁝ 393
= + ⁝ 393 remainder

The process of subtracting a larger number from a smaller number, using the tens complement, is slightly different from the example previously shown. Instead of developing a 1 in the higher place value column, a zero will be present. The complement of the apparent remainder will indicate the actual negative remainder.

Example: Subtract 362 from 127

Solution: Write

127 minuend
- 362 subtrahend

then

127 minuend
+ 638 tens complement of subtrahend
0 ⁝ 765 apparent remainder
= - ⁝ 235 tens complement of apparent remainder

which is

- 235 actual negative remainder

SUBTRACTION BY COMPLEMENTS (BASE TWO).—Digital computers use the complementary addition technique for subtraction, which has been discussed in decimal notation; and they also use the base two system. The process for base two is similar to base ten.

The ones complement of a binary number is that number with all 1 digits changed to 0's and all the 0 digits changed to 1's. This process is termed inversion. Therefore, the ones complement of 10110 is 01001. The twos complement of a binary number is its ones complement plus 1; that is,

Number	Ones complement	Twos complement
01	10	11
111	000	001
1110	0001	0010

Notice that the number 01 plus its twos complement 11 equals 100 which is a 1 in the next higher place value column followed by zeros.

The twos complement may also be determined by inverting every digit after the first one (1); that is, starting with the smallest place value and moving toward the largest place value (right to left). This method is normally less time consuming than determining the ones complement and then adding one to form the twos complement. For example: the twos complement of

001101011 ⁝ 10 The first one (from
invert all ⁝ right to left) does
is ⁝
110010100 ⁝ 10 not invert.

This indicates that the same procedure used for decimal numbers may be used for binary numbers to perform subtraction by the addition of the complement.

Example: Subtract the binary number 01101 from the binary number 11001.

Solution: Write

11001 minuend
- 01101 subtrahend

then

11001 minuend
+ 10011 twos complement of the subtrahend
1 ⁝ 01100 difference
= + ⁝ 01100 positive difference

Notice that the same number of place value columns must be used in both the subtrahend and minuend.

Example: In binary, subtract 1110 from 1111.

Solution: Write

1111 minuend
- 1110 subtrahend

then

```
     1111   minuend
   + 0010   twos complement of the subtrahend
   --------
    1|0001  difference
 ----|
 = +|0001   positive difference
 ----'
```

As in the decimal system, if a one is developed, it indicates plus. If a zero is present, it indicates a negative apparent answer and the complement of the apparent answer is used, preceded by a minus sign.

Example: In binary, subtract 1011 from 1001.

Solution: Write

```
   1001  minuend
 - 1011  subtrahend
 ------
```

then

```
     1001   minuend
   + 0101   twos complement of the subtrahend
   --------
    0|1110  apparent difference
 ----|
    -|0010  twos complement of the apparent dif-
     |      ference
 ----|
    -|0010  negative difference
 ----'
```

Multiplication

The direct method of multiplication of decimal numbers is shown in the following example.

Example: Multiply 32 x 25

Solution: Write

25 = 20 + 5

then

32 (20 + 5)

Using the distributive principle

```
   32 (20 + 5)
 = 32 (20) + 32 (5)
 = 640 + 160
 = 800
```

The same problem written as

```
   32
 x 25
 ----
```

gives

```
   32 x 5
 = 160  partial product
```

and

```
   32 x 20
 = 640  partial product
```

then

```
   160 + 640
 = 800  product
```

The technique generally used is

```
   32
 x 25
 ----
  160
  64
 ----
  800
```

Notice that the 64 really represents 640, but the zero is omitted.

Direct binary multiplication uses the same technique as direct decimal multiplication.

Example: Multiply the following binary numbers.

110 and 1101

Solution: Write

```
     1101
    x 110
  -------
     0000
    1101
   1101
  -------
  1001110
```

This may be verified by changing the factors to decimal, multiplying and obtaining the decimal product, then changing the decimal product back to binary.

Repetitive Addition

The idea that multiplication is repetitive addition is of beneficial use when working with computers. When multiplication is to be accomplished with a computer, the process of repeated addition is used.

If two numbers are to be multiplied together, write the following:

Multiply

231 by 45

Write

231 (40 + 5)

then

(231 x 40) + (231 x 5)

Multiplying each term gives the following:

$$\begin{array}{r} 231 \\ \underline{\times\ 40} \\ 9240 \end{array} \quad \text{and} \quad \begin{array}{r} 231 \\ \underline{\times\ 5} \\ 1155 \end{array}$$

Notice that 231 could have been added forty (40) times to satisfy one half of the above problem and 231 could have been added five (5) times to satisfy the other half.

$$\left.\begin{array}{r} 231 \\ 231 \\ 231 \\ 231 \\ '' \\ '' \\ '' \\ +\ 231 \end{array}\right\} \text{40 times} \qquad \left.\begin{array}{r} 231 \\ 231 \\ 231 \\ 231 \\ +\ 231 \end{array}\right\} \text{5 times}$$

$$9240 \qquad\qquad 1155$$

Rather than write 231 forty times, 2310 could have been written four times; that is,

$$\begin{array}{rl} & 231 \times 40 \\ = & 231 \times 4 \times 10 \\ = & 231 \times 10 \times 4 \\ = & 2310 \times 4 \\ & \\ = & 2310 \\ & 2310 \\ & 2310 \\ + & \underline{2310} \\ & 9240 \end{array}$$

$$9240 + 1155 = 10395$$

When the repetitive addition type of multiplication is used in a computer, it would appear as follows. Two registers are used; that is, the accumulator and the multiplier. The accumulator maintains a constant subtotal and the multiplier keeps account of the addition to be performed

The problem is to multiply 231 by 45.

Accumulator	Multiplier	
000000 + 000231	45	These operations represent the five ones
000231 + 000231	44	
000462 + 000231	43	
000693 + 000231	42	
000924 + 000231	41	
001155 + 002310	40	These operations represent the four tens
003465 + 002310	30	
005775 + 002310	20	
008085 + 002310	10	
0010395	00	

Notice that the multiplier indicated the number of times the number 231 was added and the accumulator maintained the subtotal. When the multiplier indicated 40, the 231 was changed to 2310 and the multiplier then would indicate addition of the 2310 four times. The overall effect was to move the zero in the 40 to the 231.

The binary system follows the previous techniques as shown in the following example. Multiply 1011 by 1101.

Accumulator	Multiplier
00000000	1101
+ 00001011	
00001011	1100
+ 00101100	
00110111	1000
+ 01011000	
10001111	0000

Division

The direct method of division of decimal numbers is shown in the following example:

Example: Divide 30 (dividend) by 5 (divisor).

Solution: Write

$$5\,\overline{)30}$$

Five is not contained in 3 but is contained in 30. How many 5's are contained in 30? The answer is 6, so write 6 above the zero

$$\begin{array}{r} 6 \text{ (quotient)} \\ 5\,\overline{)30} \end{array}$$

Multiply the 6 and 5 together and find the product which is 30. Write 30 under the 30 and subtract.

$$\begin{array}{r} 6 \\ 5\,\overline{)30} \\ \underline{30} \\ 0 \end{array}$$

There are no 5's in zero; therefore, the answer is 6.

Direct binary division follows the same procedure.

Example: Divide 1110 by 111.

Solution: Write

$$111\,\overline{)1110}$$

There is one 111 in 111 so write 1 above the right hand one in 111 as follows:

$$\begin{array}{r} 1 \\ 111\,\overline{)1110} \end{array}$$

Multiply 111 by 1 and write the product under the 111, and subtract, and bring down the last zero.

$$\begin{array}{r} 1 \\ 111\,\overline{)1110} \\ \underline{111} \\ 0000 \end{array}$$

There are no 111's in 0000; therefore, write zero after the 1 in the answer and find 10 is the answer.

$$\begin{array}{r} 10 \\ 111\,\overline{)1110} \\ \underline{111} \\ 0 \\ 0 \end{array}$$

Example: Divide 10010 by 110, all in binary.

Solution: Write

$$\begin{array}{r} 1 \\ 110\,\overline{)10010} \end{array}$$

Multiply quotient and divisor and subtract from dividend

$$\begin{array}{r} 1 \\ 110\,\overline{)10010} \\ \underline{110} \\ 11 \end{array}$$

Bring down last zero.

$$\begin{array}{r} 1 \\ 110\,\overline{)10010} \\ \underline{110} \\ 110 \end{array}$$

Find 110 goes into 110 one time and write

$$\begin{array}{r} 11 \\ 110\,\overline{)10010} \\ \underline{110} \\ 110 \end{array}$$

Multiply quotient and last dividend digit and find

$$\begin{array}{r} 11 \\ 110\,\overline{)10010} \\ \underline{110} \\ 110 \\ \underline{110} \\ 000 \end{array}$$

and the answer is 11.

Repetitive Subtraction

In multiplication, repeated addition is used; in division, repeated subtraction is used.

If one number (the dividend) is to be divided by another number (the divisor), write the following:

Divide 126 by 6

Write

$$\begin{array}{r} 126 \\ \underline{-\ 6} \\ 120 \\ \underline{-\ 6} \\ 114 \\ \underline{-\ 6} \\ 108 \\ \underline{-\ 6} \\ '' \\ '' \end{array}$$

Subtracting 6 from 126 twenty-one times registers a zero remainder.

A computer does the same thing except it utilizes powers of ten.

Use is still made of the accumulator and register as in repetitive addition but the technique is operated in reverse order.

Example: Divide 40320 by 126.

Accumulator	Quotient register	
40320		(a) Put the dividend in the accumulator.
	0000	(b) Set the register to zero.
- 12600		(c) Put the divisor in the largest power of ten that is equal to or less than the value of the dividend that is in the accumulator.
	+ 0100	(d) Put the power of ten into the register.
27720		(e) Subtract.
	+ 0100	(f) Add the sums in the quotient register.
- 12600	+ 0100	(g) Repeat steps (c), (d), (e), and (f) as shown.
15120	0200	
- 12600	+ 0100	
2520	0300	
- 1260	+ 0010	
1260	0310	
- 1260	+ 0010	
0000	0320	Answer

Example: Divide 126 by 6.

Accumulator	Quotient register	
126	000	
- 60	+ 010	
066	010	
- 60	+ 010	
006	020	
- 6	+ 001	
000	021	Answer

The same procedure applies to binary division except the highest power of 2 (in binary) is used.

Example: Divide 100111 by 11.

Accumulator	Quotient register	
100111	00000	
- 11000	+ 01000	Add 2^3 to quotient register.
1111	01000	
- 1100	+ 00100	Add 2^2 to quotient register.
11	01100	
- 11	+ 00001	Add 2^0 to quotient register.
0	01101	Answer

CODING

As stated previously, electronic circuit elements of computers are inherently binary; that is, they will have two stable states. Therefore, the base ten numbering system cannot be used efficiently in computers. While people communicate and calculate using letters of the alphabet and numbers of the decimal system, digital computers communicate and calculate using groups of binary symbols called codes.

Coding is the means by which data in one form is represented in another form which is acceptable to the computer. A form of coding is used in the Morse code in which letters are represented by dots and dashes. This makes the alphabet acceptable to transmission by radio.

Of the many coding systems, three of the most common ones are discussed. It should be understood that memorization of these codes is not necessary, but the understanding of the reasons for the codes is desirable.

BINARY CODED DECIMAL (B.C.D.)

This code makes use of groups of binary bits (binary symbols) to represent a decimal digit. In the decimal system there are only ten digits; therefore, only ten groups of binary bits must be remembered, EACH DECIMAL DIGIT IS REPRESENTED BY A GROUP OF FOUR BINARY BITS. The ten groups to remember are as follows:

Decimal digit	Binary - coded decimal digit			
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1

To write ten in B.C.D., the use of two groups is required; that is,

Decimal 1 0
B.C.D. 0001 0000

Any two-digit decimal number requires two groups of B.C.D. etc.

Decimal 7 3 8
B.C.D. 0111 0011 1000

The separation of the B.C.D. groups is shown for ease of reading and does not necessarily need to be written as shown; 738 could be written as 011100111000. One advantage of the B.C.D. over true binary is ease of determining the decimal value. This is shown as follows:

B.C.D. 0111 ⁝ 0011 ⁝ 1000
= decimal 7 ⁝ 3 ⁝ 8

738 in true binary is 1011100010
and, true binary 1011100010

$$= \text{decimal } 1(2^9) + 0(2^8) + 1(2^7) + 1(2^6) + 1(2^5) + 0(2^4) + 0(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$$

$$= 512 + 128 + 64 + 32 + 2 = 738$$

The ease of converting from decimal to B.C.D. and from B.C.D. back to decimal should be apparent.

One serious disadvantage of the B.C.D. is that this code cannot provide a decimal carry. The following examples are given to show this.

Example: Add the following:

Decimal		B.C.D.
5	=	0101
+ 3	=	0011
8	=	1000

Notice that there was no carry in the decimal addition and the answer in B.C.D. is equal to the answer in decimal. The B.C.D. is in correct notation and does exist.

Example: Add the following:

Decimal		B.C.D.
8	=	1000
+ 5	=	0101
13	=	1101

Notice that the B.C.D. answer is correct in true binary, but $1101_{(2)}$ does not exist in B.C.D. The correct B.C.D. answer for 13 should be 0001 0011. Therefore, when a carry is made in decimal, the B.C.D. cannot indicate the correct answer in B.C.D. form.

Excess Three Code

The excess three code is used to eliminate the inability of the binary carry. It is really a modification of the B.C.D. so that a carry can be made.

To change a B.C.D. number to excess three, add three to the B.C.D.; that is,

B.C.D.	1000
	+ 0011
Excess three	1011

In excess three code 1011 is 8 in decimal. The following chart shows the decimal, B.C.D., and the excess three code.

Decimal	B.C.D.	Excess three
0	0000	0011
1	0001	0100
2	0010	0101
3	0011	0110
4	0100	0111
5	0101	1000
6	0110	1001
7	0111	1010
8	1000	1011
9	1001	1100

As previously stated, the excess three code will provide the capability to carry in binary. The following is given for explanation.

Example: Add $6_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal		Excess three with three groups possible		
6	=	0011	0011	1001
+ 3	=	0011	0011	0110
9				

Notice that in group one the six and three are indicated. In groups two and three a zero (0011) in excess three is indicated.

Add as follows

0011	0011	1001	(Excess three)
0011	0011	0110	(Excess three)
0110	0110	1111	(Excess six)

But our answer is in excess six. Therefore, three must be subtracted from each group in order to return our answer to excess three.

0110	0110	1111	
- 0011	- 0011	- 0011	
0011	0011	1100	(Excess three)
0	0	9	Answer in decimal

When a carry is developed in any group, the following procedure is used.

Example: Add $9_{(10)}$ and $3_{(10)}$ in excess three.

Solution: Write

Decimal	Excess three				
9	0011	0011	1	1100	(Excess 3)
+ 3	0011	0011		0110	(Excess 3)
12	0110	0111		0010	(Excess 6)

NOTE: Since group one created a carry, as shown, three must be added instead of subtracted in order to place group one into excess three. The other groups follow the previous example.

0110	0111	0010	(Excess six)
- 0011	- 0011	+ 0011	
0011	0100	0101	(Excess three)
0	1	2	

The above procedure will hold for any number of group indicators the computer possesses.

A further advantage of excess three code is the ease with which the nines complement of a number indicated in excess three may be found; that is, the nines complement of 7, indicated in excess three as 1010, is found by inverting each digit in 1010 to read 0101. This 0101, in excess three, is 2 which is the nines complement of 7.

The following table shows the nine complement of the decimal digits.

Decimal	Excess three	Excess three inverted	Nines complement
0	0011	1100	9
1	0100	1011	8
2	0101	1010	7
3	0110	1001	6
4	0111	1000	5
5	1000	0111	4
6	1001	0110	3
7	1010	0101	2
8	1011	0100	1
9	1100	0011	0

GRAY CODE

This code is a modification of the binary counting system. In the Gray code sequence counting, only one bit will change as each count proceeds. When counting in binary from $7_{(10)}$ $(0111_{(2)})$ to $8_{(10)}(1000_{(2)})$, notice that four bits had to be changed.

The Gray code is shown for comparison

Decimal number	Pure binary	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111

In the Gray code when counting from $7_{(10)}(0100)$ to $8_{(10)}(1100)$, notice that only one bit changed.

One of the primary purposes of this code is the reduction of operational errors by changing only one digit at the time during the process of converting mechanical changes into numerical expressions. For example, to convert the shaft rotation (output of an analog computer) from seven to eight degrees would require only a change of one bit as previously indicated.

To convert a binary code to its Gray code equivalent, the following addition WITHOUT CARRY is used.

Example: Convert binary 0100 to its Gray code equivalent.

Solution: Keep the most significant bit as is.

Binary	0	1	0	0
Gray	0	_	_	_

Next, add horizontally the most significant bit to the next significant bit in the binary number and carry the sum to the Gray code as follows:

Binary 0 1 0 0

Gray 0 ① _ _

now add and continue as shown

Binary 0 1 0 0

Gray 0 1 ① _

then

Binary 0 1 0 0

Gray 0 1 1 ⓪

Therefore, 0100 binary is equivalent to 0110 in the Gray code.

Example: Convert $14_{(10)}$ to Gray code.

Solution: Write

Decimal 14 = 1110 binary

Binary ① 1 1 0

Gray ① _ _ _

then

Binary 1 1 add without

Gray 1 ⓪ _ _ the carry

then

Binary 1 1 1 0

Gray 1 0 ⓪ _

then

Binary 1 1 1 0

Gray 1 0 0 ①

therefore, 1110 binary is equivalent to 1001 in Gray code.

A method is also needed to convert Gray code to binary code.

Example: Convert 1101 in Gray code to binary.

Solution:

Gray ① 0 0 1 Retain the most significant

Binary ① _ _ _ Gray code bit.

Gray 1 ⓪ 0 1 Add diagonally without a

Binary ① 1 _ _ carry.

Gray 1 0 ⓪ 1 Continue diagonal addition

Binary 1 ① 1 _

Gray 1 0 0 ① Continue.

Binary 1 1 ① 0 Therefore, Gray 1001 is equivalent to binary 1110.

OCTAL NUMBERS

Octal numbers are base eight numbers; that is, there are only eight digits in base eight. These are 0, 1, 2, 3, 4, 5, 6, and 7. Because eight is a power of two, the octal system has special characteristics that make it especially useful in situations involving binary numbers. This is illustrated as follows:

A decimal number can be converted to octal by the same method described for decimal to binary; that is, to change 334 to octal write

	Remainder
8/334	
8 /41	6
8 / 5	1
0	5

Therefore,

334 decimal = 516 octal or $516_{(8)}$

The same decimal number when changed to binary is 101001110.

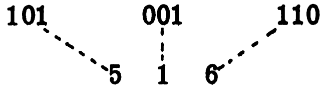
Since things equal to the same thing are equal to each other

$$516_{(8)} = 101001110_{(2)}$$

Notice that the true binary number is separated into groups of three digits from the right as follows:

101 001 110

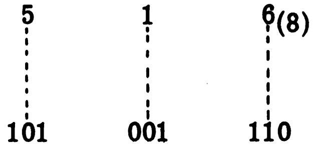
and by observation, notice that each group represents the following:



which is 516 in octal.

To convert from binary to octal, it is only necessary to divide the binary number into groups of three and read each group as the octal representation in place value.

To convert from octal to binary, the reverse operation is used; that is,



Example: Convert 40 decimal to octal, then to binary.

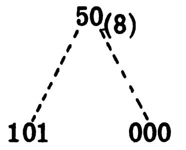
Solution: Write

8/40 Remainder
8/ 5 0
5

Therefore,

$$40_{(10)} = 50_{(8)}$$

and then

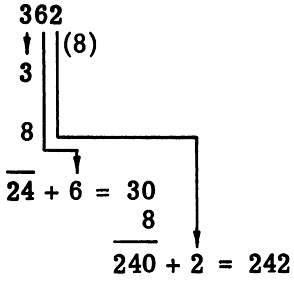


The preceding conversions from binary to octal and from octal to binary are possible because 2^3 is the same as 8^1.

The octal number system affords many conveniences. When recording a binary number on paper, it is usually more convenient to write it in octal. For example, computer programers and programing manuals use the octal system as a convenient notation for binary numbers. Also, when converting a large decimal number to binary, it is usually more convenient to convert it to octal first and then to binary since fewer divisions are required in dividing a decimal number by 8 instead of 2.

A number in any base that is smaller than ten can be converted to a number in base ten (decimal) by the following method: Multiply the most significant digit (MSD) by the present (old) base, add the next MSD to the product of the last multiplication and multiply the sum by the present (old) base, continuing until the least significant digit (LSD) is added.

Example: Convert to decimal



BASIC PRINCIPLES

In contrast to analog devices, digital computers use discrete values to represent the digits 1 and 0, and the computations are performed by simple electronic switches and circuits. A fundamental difference between the two types is that the analog computer is continuously presenting a solution to the problem, while the digital computer performs each computation separately. In other words, when one of the factors in a problem changes, the solution presented by the analog computer changes continuously as the inputs change. In a digital computer, the entire computation must be done again after each increment of change in the input.

Most of the computers used in naval aviation are part of control systems where time is a factor in the problem. The computer receives information from radar and other sources, and makes decisions, which are presented at the output to control some specific operation, such as an airborne interception.

An automatic digital computer generally consists of five major units: input, control, memory, arithmetic, and output. A simple block diagram appears in figure 14-1.

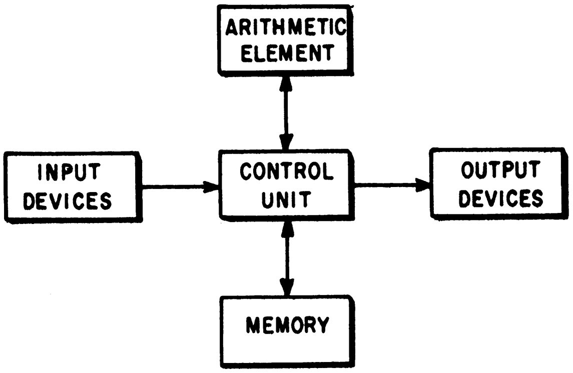


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Figure 14-1.—Digital computer elements block diagram.

INPUT UNIT

For a computer to perform a specified series of operations, it must be fed both the instructions and the data to be used in the computations. Many different devices are used to properly present the information to the computer. Examples are modified electric typewriters, punched card and punched tape readers, magnetic tape readers, and manual input devices such as pushbuttons or toggle switches. In airborne applications, the most common input device is the analog to digital converter which changes the proportional voltage and current analogs into the digital form required by the numbering system used in digital computers.

CONTROL AND ARITHMETIC UNITS

The control unit in a digital computer interprets the instructions of the program and controls the actions of all other sections of the computer. It prescribes the exact sequence of events for all operations.

All of the mathematical operations are performed in the arithmetic unit of the computer. Addition, subtraction, multiplication, and division are performed when specified in the program, under the direction of the control unit. Results of these operations can then be put in the memory for future use.

MEMORY UNIT

The memory or storage section of the computer is used to store the information which is used during the computational process. It stores both the program instructions and the data used in the computation. The memory can be used to hold both intermediate and final results as the computer goes through the program. Common memory devices include: magnetic cores, magnetic drums, magnetic tapes, ultrasonic delay lines, and flip-flops.

Figure 14-2 shows a magnetic core memory. Each core can be magnetically saturated to either the 1 or the 0 polarity. Therefore, each core can hold just one bit of data at a given time.

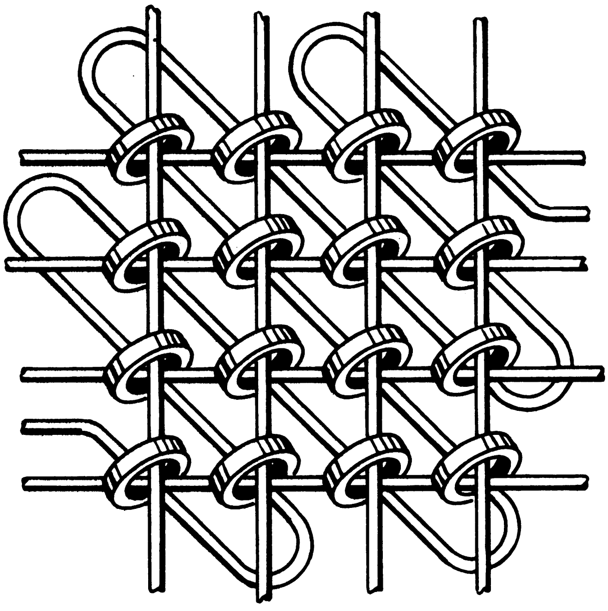

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Figure 14-2.—Magnetic core memory cell.

Regardless of the type of memory employed, it is divided into a number of locations, each of which is identified by an address. When the control unit calls for an instruction from the program or a piece of information which is stored in the memory, it acquires the information by using the proper address to establish the path to the appropriate memory element and the data stored there. The normal construction of storage devices makes any address accessible. However, the length of time required to obtain the information is determined by the type of storage device. This type of accessibility is referred to as random or sequential access.

The information stored at each address is referred to as a "word." Each word is represented by a number of pulses or signal voltage levels. The storage can be accomplished on tape, magnetic devices, or special circuits. A word can represent either a numerical quantity or a computer instruction, but only one word can be stored in any given address.

OUTPUT UNIT

After the computer has done the computations, there must be some method of communicating the results to the operator. The devices used to "read out" the results are similar to those used in the input: punched cards or tape, magnetic tape, and so forth. Specialized output devices include audio or video displays and digital to analog converters.

Several special facilities are included in digital computers. When an operation is to be performed in an arithmetic unit, only one word at a time can be transferred from the memory unit. To perform an operation with two words, the first word must be stored momentarily while the second word is being transferred. For this function, the arithmetic unit has a special memory cell called an accumulator.

The accumulator is one of a class of memory devices called registers. A register is simply a means of storing temporarily a certain amount of information. The methods of storage may be the same as those used in the memory, but the register can only store one word at a time. Other registers are used in the computer, such as the instruction register associated with the control unit which allows reference to the instruction being interpreted during the time control signals are being set up.

BINARY NUMBER SYSTEM

Words are memorized by the computer as binary numbers. A word is composed of a series (or train) of 1 and 0 signal voltage levels, or pulses. The number of bits (1 or 0 symbols) in the word is called the length of the word. The speed of a computer is denoted by the rate at which the pulses pass a given point, or equivalently by the pulse repetition frequency. The circuits which manipulate the pulse trains are called gates, logic circuits, or digital switching circuits.

All the pulses in a computer are normally synchronized with respect to each other by means of a clock pulse, which is driven by an oscillator whose frequency is an integral multiple of the speed of the computer.

Figure 14-3 shows a typical word and the waveform of its associated pulse train. In this case, the length of the word is seven bits. The corresponding clock pulse train is also shown. In this figure, a pulse represents a 1, and the lack of a pulse represents a 0 symbol.

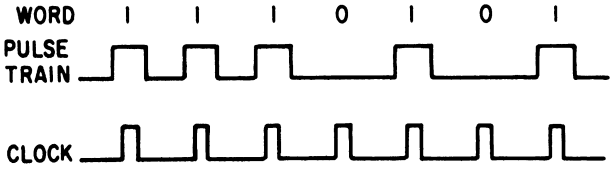

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Figure 14-3.—Waveform of seven-bit word and its clock pulses.

SYMBOLIC LOGIC

The operations performed by a digital computer are based on a logical reasoning process. Since the rules for the equations and manipulations employed by the computer differ from the ordinary rules of arithmetic, understanding this subject requires some discussion of the basic concepts involved.

It should be recalled, from the review of Basic Electronics, NavPers 10087-C, that the symbolic operations utilized in digital computers are based on the investigations of George Boole, and the resulting algebraic system is called Boolean algebra. It is similar to the algebra with which we are all familiar, but it follows different rules.

To understand Boolean notation, the technician must ignore some of the things he has learned about the arithmetic use of the dot and plus connectives, as their use in logical operations is different from the arithmetic usage.

The equations which characterize Boolean algebra are given in table 14-1. Notice that

Table 14-1.—Equations of Boolean algebra.

Law	Part 1	Part 2
1. Identity	$A = A$	$\bar{A} = \bar{A}$
2. Intersection	$A.1 = A$	$A.0 = 0$
3. Union	$A + 1 = 1$	$A + 0 = A$
4. Complementary	$A\bar{A} = 0$	$A + \bar{A} = 1$
5. Idempotent	$AA = A$	$A + A = A$
6. Commutative	$AB = BA$	$A + B = B + A$
7. Associative	$A(BC) = ABC$	$A + (B+C) = A + B + C$
8. Distributive	$A(B+C) = AB + AC$	$A + (BC) = (A+B)(A+C)$
9. Absorption	$A(A+B) = A$	$A + (AB) = A$
10. DeMorgan's Theorem	$\overline{(AB)} = \bar{A} + \bar{B}$	$\overline{(A+B)} = \bar{A}\,\bar{B}$
11. Double Negative	$\bar{\bar{A}} = A$	
12. Unnamed Laws (2)	$A(\bar{A}+B) = AB$	$A + \bar{A}B = A + B$
13. Unnamed Law	$\bar{A} + AB = \bar{A} + B$	$\bar{A} + A\bar{B} = \bar{A} + \bar{B}$

some of the rules are quite different from those of ordinary algebra.

Those interested in Boolean algebra should refer to Mathematics, Vol. 3, NavPers 10073-A, or Digital Computer Basics, NavPers 10088, for additional information.

The three basic functions needed for representation of expressions such as those in table 14-1 are the AND function, the OR function, and the NOT function. The meanings of these are discussed in Basic Electronics, NavPers 10087-C.

Electronic circuits which are used in mechanizing the AND, OR, and NOT functions are described in the following paragraphs. Closely related to these are the inhibitor circuit and the EXCLUSIVE OR circuit, which are also discussed.

LOGIC CIRCUITS

Logic circuits are the hundreds of high speed electronic switching circuits of a digital computer that store information signals and perform logical operations on the information signals. In the first case, the pulse trains representing information are stored temporarily in circuits such as registers, which can be made up of multivibrators. In the second function, circuits such as the basic NOT, OR, and AND types perform logical operations. These circuits sense the input conditions and produce an output only if certain input conditions exist. This is one of the reasons for their names. They can also be generally classed as gate circuits.

A digital computer will generally contain a great many of these logic circuits, but the types of circuits contained will be limited to the smallest number that can perform the required functions. This improves maintainability. The circuits may use vacuum tubes, transistors, diodes, tunnel diodes, silicon rectifiers, or other elements such as magnetic cores. No attempt is made to cover all variations of all types of logic circuits. Coverage will be limited to a representative few of each type in order to present an idea of their nature and use.

NOT FUNCTION

The NOT circuit, also known as an inverter circuit, is probably the simplest of all. It is nothing more than a normal gate amplifier stage that produces an inversion (negation) of the input signal and has unity gain.

Figure 14-4 is a NOT circuit employing a PNP transistor in a common emitter configuration. When no signal is applied, Q1 is biased to cutoff by the voltage divider, consisting of R2 and R3, which makes the base positive with respect to the emitter. The input signal is divided by R1 and R2, making the circuit gain equal to unity. Note that the input signal must be negative to cause conduction and that the output developed across Q1 is the opposite of the input.

Note that any device or circuit that inverts a signal between the input and output with unity gain meets the definition of a NOT circuit. One commonly used NOT circuit device is the transformer.

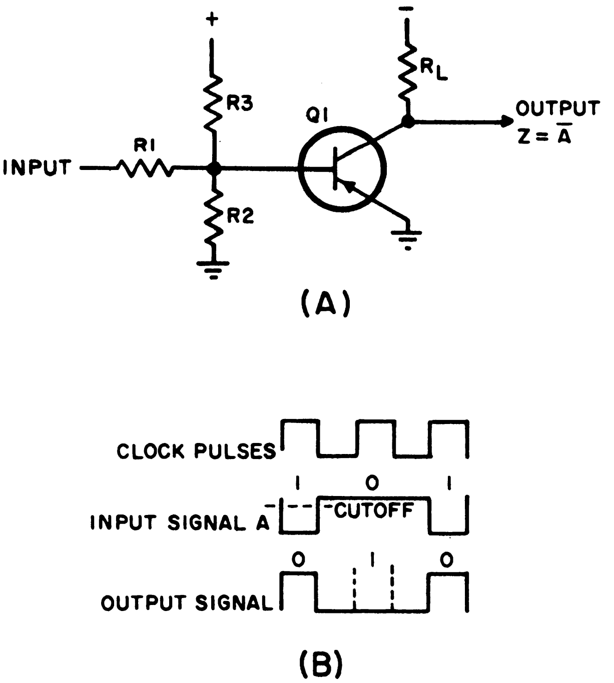

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Figure 14-4.—(A) Transistor NOT circuit; (B) waveforms showing inversion between input and output.

OR FUNCTION

An OR circuit is a logic circuit that has two or more inputs and produces an output if any or all inputs are applied. It is very similar to an audio mixer stage, since several inputs can be applied from different sources without interaction upon the sources; and any input signal produces an output signal.

Diode Circuit

The simplest of all OR circuits is probably a diode circuit such as figure 14-5. Again, four inputs are shown; and it is assumed that the signals are positive with respect to ground. In that case, each diode will conduct heavily through R_L and the source circuit (not shown) when a positive pulse greater than about 3 volts occurs.

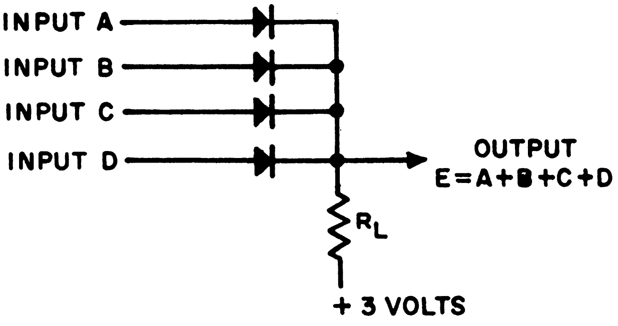

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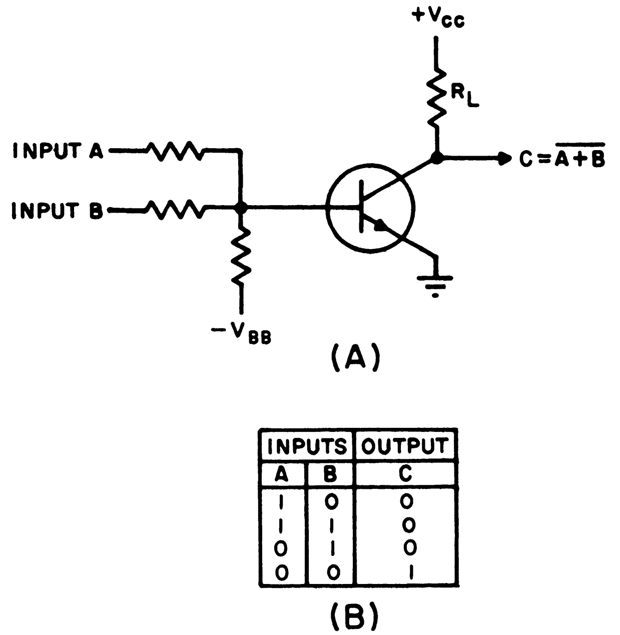
Figure 14-5.—Diode OR circuit.

The output is taken from across R_L and is not inverted. The circuit, by reversing the diodes and the polarity of the 3-volt source, will function for bit pulses that are negative with respect to ground.

Transistor Circuit

Figure 14-6 shows a transistor type OR circuit that also includes the negation function of a NOT circuit. A circuit that performs both logic functions is sometimes called a NOR circuit.

With no input signal applied, the NPN transistor is biased to cutoff by the negative bias applied between base and emitter. (See fig. 14-6.) A positive input pulse causes saturation conduction of the transistor, producing a



INPUTS		OUTPUT
A	B	C
1	0	0
1	1	0
0	1	0
0	0	1

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Figure 14-6.—(A) Transistor (NOR) circuit; (B) truth table.

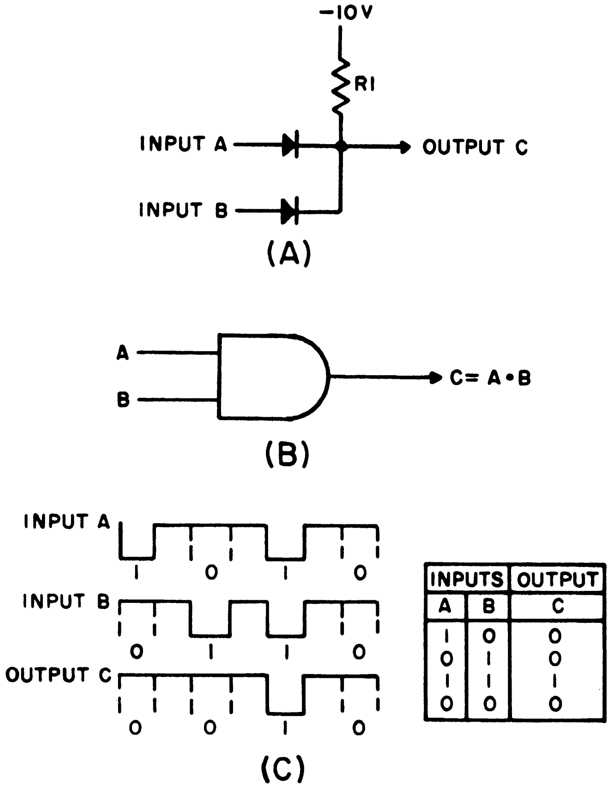
negative output pulse at the collector. The truth table shows the NOT and OR functions tabulated for various input conditions that may exist. Similar circuits could be arranged for negative input signals by biasing an NPN transistor to saturation conduction or by biasing a PNP transistor to cutoff.

AND FUNCTION

An AND circuit is very similar to the familiar coincidence circuit which has been used in other electronic apparatus for many years. All input signals must be alike (representing either all 1's or all 0's) and occur at the same time to produce a useful output. Therefore, AND circuits find wide use in interpreting control instructions and performing logical operations upon signals in the arithmetic portion of the digital computer. Several circuit configurations are possible, using various circuit elements.

Diode Circuit

The circuit of figure 14-7 uses two diodes to perform the AND function. Under static signal conditions, or with binary 0 input for both A and B, the diodes are conducting heavily through R1 and the resistances of the input circuits (not shown). The output level is therefore near zero volts. R1 is much larger than the input circuit resistance of the conduction path, and nearly all of the -10 volts is dropped across R1 because the diodes have very little forward resistance.



INPUTS		OUTPUT
A	B	C
1	0	0
0	1	0
1	1	1
0	0	0

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Figure 14-7.—(A) Diode AND circuit for negative signals; (B) block diagram symbol; (C) waveforms and related truth table.

When input A is a 1 and input B is a 0, the diode or input A is cut off. However, there is no output, because the diode in input B is conducting and essentially short circuits diode A.

When inputs A and B both represent 1's, both diodes are cut off. The output terminal then goes negative by about 10 volts. This is the third set of conditions shown in the truth table; with the signals and conditions shown, none of the other signal conditions will produce a useful output from the circuit.

By reversing the diodes and the -10 volts, an AND circuit can be produced that will handle and produce signals of exactly the opposite polarity. Also, in either case, the circuit is not limited to two input signals; three, four or five inputs are common in almost all logic circuits except the simple NOT circuits.

Transistor Circuits

Four transistor AND circuits, the first three of which also include the NOT function, are shown in figure 14-8. These are not the only circuits possible; however, they are illustrative of the wide range of AND circuit configurations possible.

The AND circuit of figure 14-8(A) uses two PNP transistors that are initially biased for saturation conduction by the negative base to emitter voltage. If both bases are driven to cutoff at the same time by positive signals, both transistors stop conducting; the collector output signal thus goes in a negative direction, producing the NAND function. Remember, this means an output pulse (negative in this case) is produced only if both A AND B are NOT negative.

The two NPN transistors of figure 14-8(B) are also statically biased for saturation conduction by the positive base to emitter voltage. When two negative input signals are applied simultaneously, both transistors are driven to cutoff; the collector output thus increases in a positive direction. If only one base is driven negative at a particular time, the other transistor continues to conduct; this keeps the output terminal at practically ground potential. The circuit thus performs as an AND NOT circuit.

The circuit of figure 14-8(C) is somewhat different. Statically, each transistor is cut off. During operation, all three must conduct together. If any transistor remains cut off, the others cannot conduct because the emitter-collector conduction paths of the three are in series. If all three transistors are driven into conduction by negative signals applied to the bases, there will be conduction; and the collector voltage at the output terminal will increase in a positive direction. The circuit thus performs as an AND NOT circuit.

Four PNP transistors are connected together at the collectors and emitters (fig. (D)) to form an emitter-follower type circuit. However, there are four separate input terminals for the

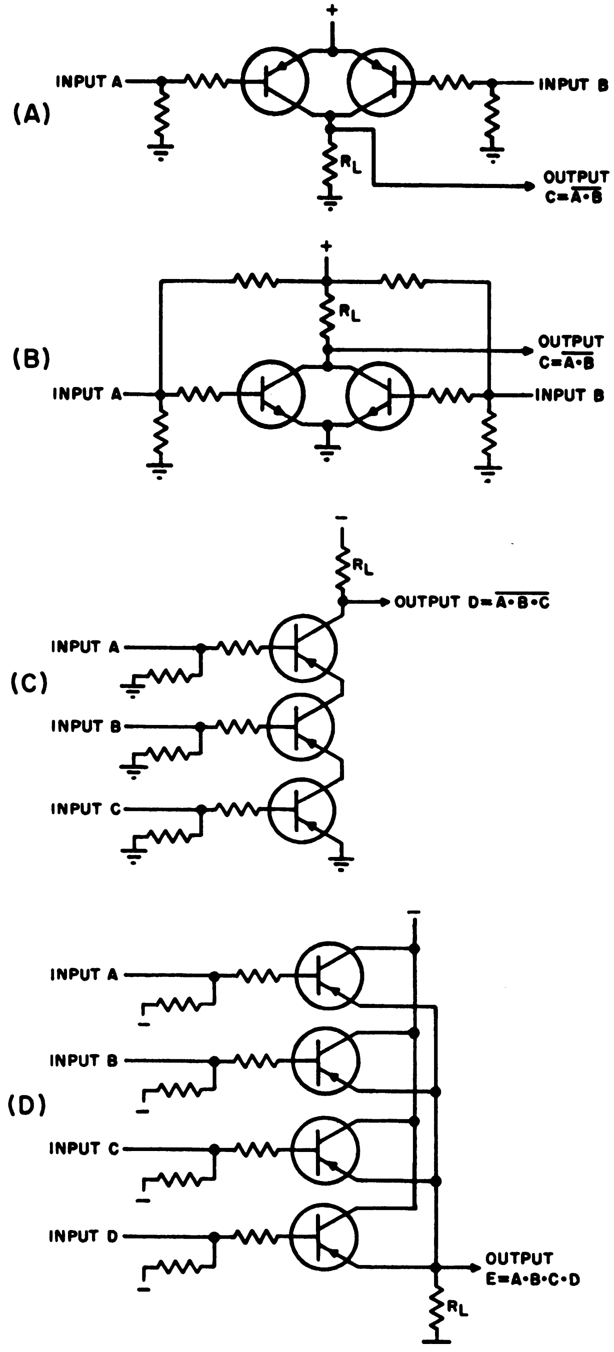

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Figure 14-8.—Examples of transistor AND circuits.

base signals. Initially, all four transistors are in saturation conduction and nearly all of the collector voltage is dropped across R_L. Again, all transistors must be cut off together to reduce the voltage drop across R_L. The application of four positive input signals to the bases will cut off each transistor, and the output terminal voltage will go in a positive direction. Note the lack of the NOT logic function; that is, the circuit does not perform as an AND NOT circuit.

INHIBITOR CIRCUITS

The combination of an AND and a NOT circuit in which the NOT circuit is inserted between one input terminal and the AND circuit is called an INHIBITOR circuit. Figure 14-9(A) shows the functional arrangement of the combination. Figure 14-9(B) shows a more commonly used block diagram symbol, where the inhibit signal input to the block is through a circle. The NOT and AND circuits can take the forms of any circuits described previously; the only requirement for the NOT circuit is that it invert the input signal.

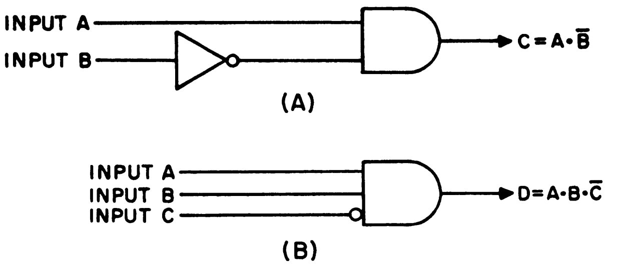

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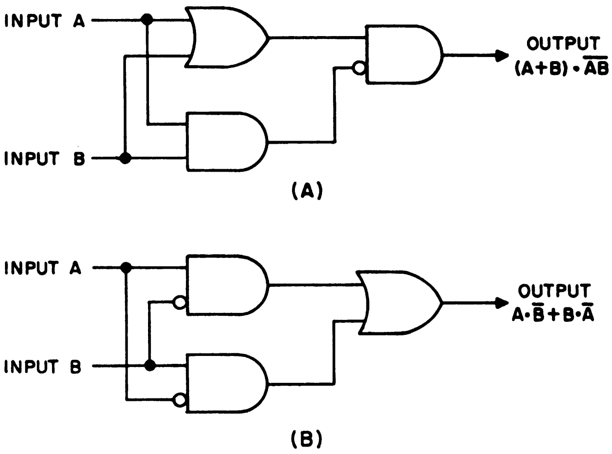
Figure 14-9.—INHIBITOR circuit (A) Two inputs; (B) three inputs.

The circuit in figure 14-9(B) produces an output under the following conditions only: One or more regular input signals are applied, but no input signal is applied to the inhibit terminal.

EXCLUSIVE OR CIRCUIT

An EXCLUSIVE OR circuit is a combination of circuits which has two input signal terminals but produces no output when two signals of like polarity are applied simultaneously. However, if only one input signal is applied; an output is produced.

Two combinations of circuits that can be used to form the EXCLUSIVE OR circuit are shown in figure 14-10. For the circuit of figure 14-10(A), input signal A will pass through the OR and INHIBITOR circuits to the output if no signal from the AND circuit reaches the inhibitor terminal. But if a signal is applied to input B, which operates the AND circuit, a signal reaches the inhibit terminal and prevents any output. In figure 14-10(B), two simultaneous input signals will prevent an output from both of the INHIBITOR circuits and the OR circuit will thus produce no output.


INPUT A
INPUT B
OUTPUT
$(A+B) \cdot \overline{AB}$
(A)
INPUT A
INPUT B
OUTPUT
$A \cdot \bar{B} + B \cdot \bar{A}$
(B)

AQ.538

Figure 14-10.—Two forms of EXCLUSIVE OR circuits.

Signals A and B are signals that occur simultaneously and are alike for the conditions of no output. Because of this characteristic, the circuits can be used to compare two pulse trains and to produce an alarm signal output when the two trains are not always identical. In this manner, two corresponding circuit points of two identical computers can be constantly examined for errors.

PULSE RESHAPING CIRCUITS

Although reshaping circuits do not, strictly speaking, perform a logic function, they use circuits that are classed as logic circuits. Their function is the reshaping of pulse trains that may have deteriorated in shape and amplitude beyond further usability. As pulse trains pass through various circuits of a computer, the rise and fall times of the pulses usually increase; the amplitude may decrease; and the pulses are delayed in time.

The clock pulses, which are usually available at several points in the computer, are used with a reshaping circuit to restore the shapes of numerical or instructional information pulses within the computer.

If the information pulses to be reshaped occur at the same time as an available clock pulse, a simple AND circuit can be used to reshape the pulse. Figure 14-11(A) shows clock pulses and deteriorated pulses applied simultaneously to terminals A and B, respectively, of an AND circuit. In a properly designed circuit, the output is produced only during the time interval t_1 to t_2. The rounded top of the output pulse can be clipped in a succeeding amplifier stage.

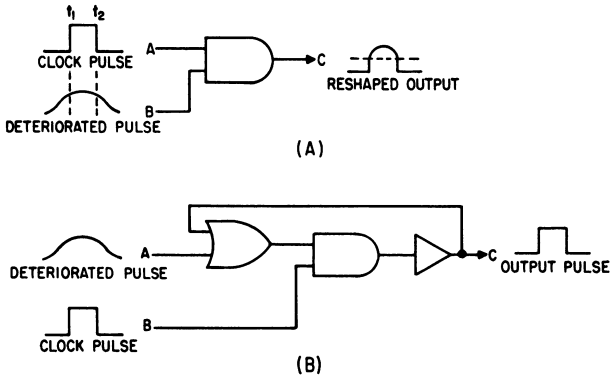


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Figure 14-11.—Block diagrams of pulse reshaping circuits.

Instances will occur where the deteriorated pulses to be reshaped are no longer in time synchronization with the clock pulses. In these cases, the circuit shown in figure 14-11(B) can be used to reshape the pulses.

The deteriorated pulses and clock pulses are applied to terminals A and B, respectively. The deteriorated pulses pass through the OR circuit and, together with the clock pulses, cause an output from the AND circuit during the portion of the time that they occur simultaneously.

If there were no regenerative (positive) feedback from the amplifier output, the output would be representative of only the overlap time of the deteriorated and clock pulses. However, the positive feedback and the clock pulse keep the AND circuit functioning, producing an input to the amplifier until the clock pulse ends. This produces an output pulse that is identical to the clock pulse. Note that this circuit allows a pulse that is not in exact time sequence with a clock pulse to be reshaped, but there must be some overlap in the duration of the two pulses.

ARITHMETIC CIRCUITS

An automatic digital computer is a vastly complicated machine with a great many electronic circuits. Although the number of circuits is high, the variety is small. That is, it consists of a large number of a few types of gate circuits. Many of the types found in the arithmetic unit were discussed in the preceding section as logic circuits. An additional type of logic circuit not previously discussed, the Eccles-Jordon multivibrator, known as a flip-flop (FF), is in wide use in the binary counters and the registers of the control and arithmetic units.

The following paragraphs discuss how the FF and other logic circuits are combined to form counters, registers, and adders; and how they perform the temporary storage, addition, subtraction, multiplication, and division functions of the arithmetic unit.

FLIP-FLOPS

In most cases, the registers in the arithmetic unit and the binary counters in the control unit are composed of FF's constructed with vacuum tubes or transistors. Where a register in the arithmetic unit uses an associated binary counter, the counter is also composed of FF's. The basic functions of a counter or register are to totalize the numbers of bits and to provide temporary storage for this information. Once a number of bits has been fed into the counter or register, the information is retained until the circuit is cleared by a reset signal or the power is removed from the circuit.

Figure 14-12(A) shows a transistorized FF circuit. Other devices that are capable of two states of operation (for example, tunnel diodes or magnetic core coils) can also be used in the construction of FF's. A block diagram symbol

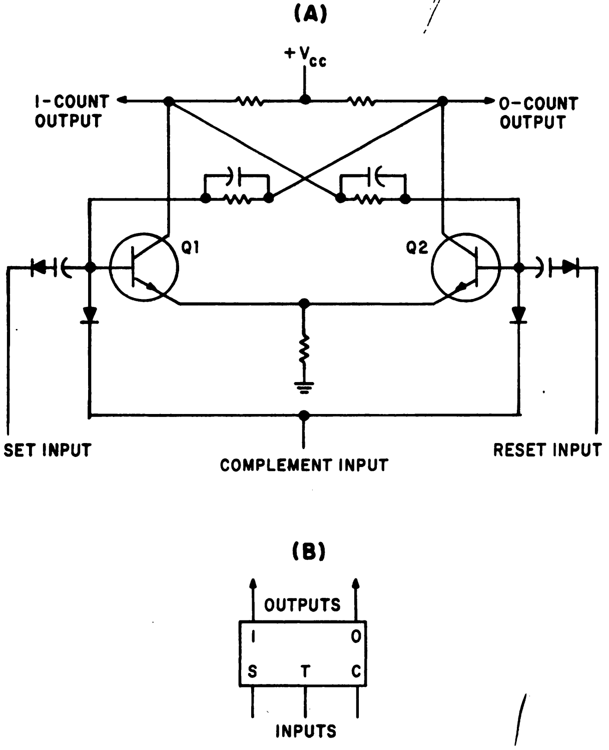

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Figure 14-12.—(A) FF using transistors; (B) FF block diagram symbol.

commonly used to represent the FF in computers is also shown in figure 14-12(B).

In the following discussion, it is assumed that the technician is familiar with the operation and general use of the FF circuit. (The basic FF circuit is discussed in Basic Electronics, NavPers 10087-C.) In digital computers, the FF circuit can have several inputs and two outputs. The circuit shown in figure 14-12(A) has three input signals: a reset input, a complement input, and a set input. Their functions are described below.

A reset input signal sets the stage to a 0 condition or clears the previous 1 count if one was present. If several stages in a counter are cascaded, the reset signal is generally connected to all stages; and they are all reset to 0 simultaneously.

The complement (trigger) input is applied to both halves of the FF, and a signal causes the stage to change from a 0 to a 1, or vice versa. In registers, the complement signal is generally a single pulse that is applied to all stages simultaneously. It produces the 1's complement of the binary number held by the register. In a counter, the complement input of only the first stage could be used as the signal input for the pulses to be counted. The signal and complement inputs can also be applied symmetrically in the plate or collector circuits.

In case the stage is in the 0 state, the set input signal flips it to the 1 state. In most counters, instead of using the complement input, the reset and set inputs of the first stage are paralleled and used for the input signal.

The three inputs use negative signals, to cause a change of state in the FF. It is sometimes desirable to design the stage for positive signals, but a FF stage can be more precisely controlled if it is switched from a state of heavy conduction than from a cutoff state. Note that each stage counts to a scale of 2, but indicates a maximum count of only 1, a 0 would be indicated for a second input pulse.

Counters

Most large computers can handle a minimum of about 34 bits, the equivalent of a 10-digit decimal number. The maximum scale for a binary counter is equal to 2^n, where n is the number of FF's. However, the maximum decimal equivalent count that the indicators will show is $2^n - 1$. Figure 14-13 shows four FF's that make up a binary counter capable of counting to the binary equivalent of decimal 16. If indicators are provided that read in the binary system, a count equal to 15 in the decimal system is indicated as 1111. The next count, which is decimal 16, changes all the indicators to 0.

The decimal positional coefficients of binary 1111 are 1, 2, 4, and 8, read from right to left. The least significant bit (LSB) is the last 1. For a count of binary 1, the binary indicators would read 0001; for this reason the drawings for binary counters and registers sometimes show the input pulses applied to the right-hand side of the chain and the signal and count progressing to the left. However, an oscilloscopic presentation of the input pulses will show the pulse that represents the LSB as the pulse which is furthest to the left on the oscilloscope screen.

A counter similar to the one shown in figure 14-13 is explained in detail in Basic Electronics, NavPers 10087-C. That explanation should be reviewed before continuing with the present discussion.

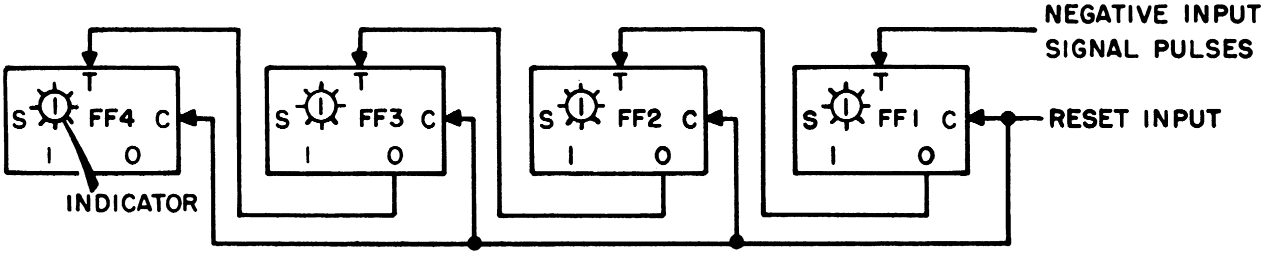

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Figure 14-13.—Binary counter at a count of 1111 (decimal 15).

It is easy to convert the counter of figure 14-13 into a decade (scale of 10) counter (fig. 14-14) by the use of feedback. In the case of decade counters, indicators which read from 0 to 9 can then be provided. Other feedback and feedforth arrangements will also convert four FF's into a decade counter.

The counter of figure 14-14 operates in the same way as the one shown in figure 14-13 with two exceptions:

1. On the fourth input pulse, FF3 flips to the 1 state, feeds back a positive pulse to the set input of FF2, and sharply flips it from the 0 to the 1 state. At this point the counter registers a decimal 6 (0110 in binary), a condition that the circuit of figure 14-13 reaches after 6 input pulses. In other words, the circuit in figure 14-14 jumps ahead by two counts after the fourth input pulse is applied.

2. The sixth input pulse flips FF4 to the 1 state; and a positive pulse is fed back to the input of FF3, sharply flipping it back to the 1 state. At this point, the circuit registers 12 (0010 in binary) since after a full count of 9 it returned to 0 at 10 and is now back up to 2, and the counter is ahead by six counts.

Otherwise, the FF's respond to the 10 input pulses in a normal manner, taking into consideration the states of FF2 and FF3 after feedback is applied.

So far, the counters have been described as counting upward; counting downward is also easily done with FF's by simply feeding the 1 output, instead of the 0 output, to the normal input of the next FF. This is frequently done in digital computers.

TYPES OF INPUT

Binary words are fed into the logic and arithmetic circuits in either of two different forms, serial or parallel, or in a combination of the two. In serial form the bits follow one another sequentially on a single input line. In parallel form, all the bits of the word are

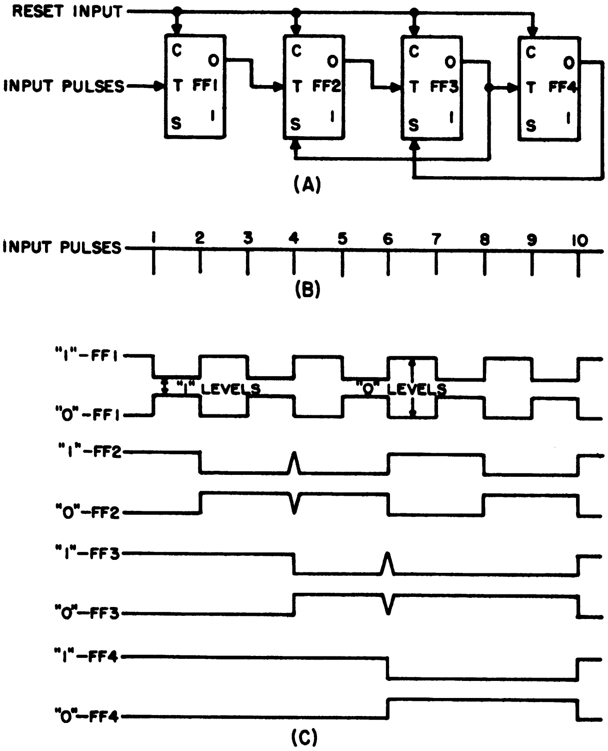

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Figure 14-14.—Conversion of a scale of 16 binary counter to a scale of 10 counter. (A) counter circuit; (B) clock input pulses; (C) waveforms.

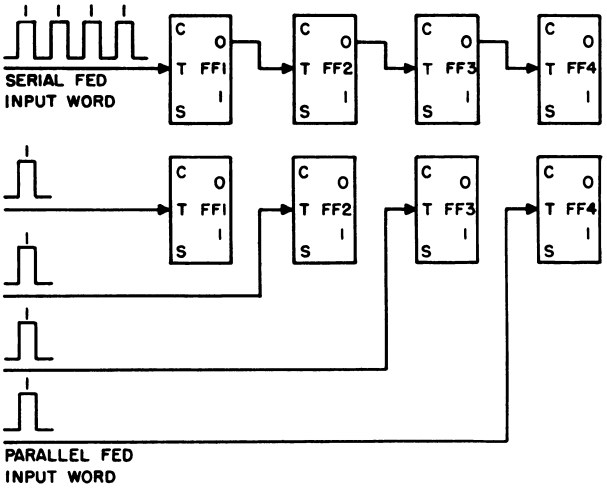

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Figure 14-15.—Examples of serial and parallel inputs.

applied simultaneously over a number of paths equal to the number of bits in the word. Figure 14-15 illustrates both methods.

Each method has advantages and disadvantages. The method used in a particular computer depends on whether extremely high speed arithmetic operations are needed or whether economy and machine simplicity are more important.

A machine with serial operation is much more economical. For example, in the case of a counter or register, a word representing decimal 15 (1111 in binary) can be handled by four FF's; and, as will be shown later, there is no limit to the word length a serial adder will handle.

A parallel counter or register for handling binary 1111 also requires four FF's, but its speed of operation is four times faster than the speed of a serial counter or register. However, 30 FF's would be required for a parallel 30-bit word. In a parallel adder, a separate adder is required for each bit of both the addend (the number that is to be added to another) and augend (the number to which another is to be added). However, the addition is completed in the same time a serial adder requires to add one-bit addend and augends. The complexity of a parallel arithmetic unit over a serial unit is multiplied by the word length.

REGISTERS

A register is a device that provides temporary storage of a binary word during computation. Registers are composed of FF's and are generally found in the control and arithmetic units of digital computers. There may be several in a large computer; however, an arithmetic unit may contain only one or two. The number depends on the amount and variety of other storage facilities that are included. It is also somewhat dependent upon the speed with which the computer is designed to operate. A relatively long time is required for readout of a word from a magnetic drum memory; a shorter readout time is possible with magnetic core matrix and sonic delay line type memory units. Generally, one or more arithmetic registers can be used to advantage in speeding up the computation.

Remember that a word is a group of pulses; each pulse, or lack of one, represents a bit; each bit represents a binary digit of 1 or 0. The chain of bits can be of almost any length; the maximum is usually about 34 bits. This group of pulses at the input unit can represent instructions, constants, and variables for the problem. In the actual arithmetic circuits, the pulse chains that represent the constants and variables for the problem are present. The instruction portion of the word is used to program the computer.

Storage Register

A storage register is used to store a word temporarily. Storage registers consist of a group of FF's capable of storing the maximum word length expected; they operate in the same fashion as counter FF's. Figure 14-16 represents a storage register which is capable of handling a 4-bit word. The lower group of FF's comprise the register, and the upper group form an associated counter. Between the two is a group of AND circuits. Note that the input to the counter is in serial form and the input to the register is in parallel form; therefore, it also forms a serial to parallel converter for the word. (The counter is included in the set because of this function as a converter.) First, the word is applied to the counter. Later a read pulse is applied to the AND circuits. If the read pulse and the voltage at the 1 output of a particular counter FF agree in voltage levels, a 1 pulse is transmitted to the corresponding

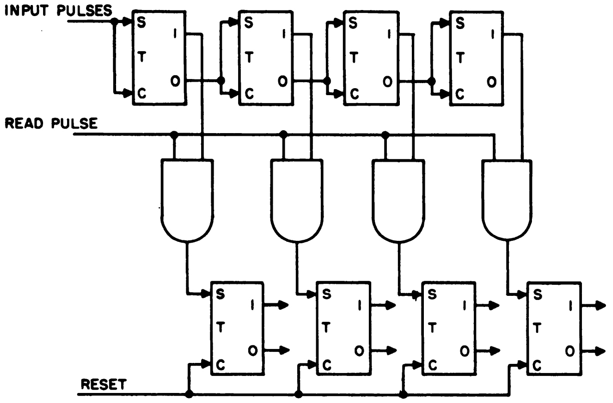

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Figure 14-16.—A four-bit register and associated counter.

register FF. No signal is transmitted to a register FF if the 1 output of the corresponding counter FF is at a 0 voltage level or, in any case, until there is a read pulse applied.

Each register FF can store a single bit, representing a 1 or 0. Note that at the same time a 1 is represented by a 1 level of voltage at the 1 output terminal, a 0 voltage level is represented by the 0 output terminal. In other words, if a 1 output represents A, the 0 output represents $\bar{A}$. The output from the lower FF's (fig. 14-16) might be applied to the augend or addend terminals of a parallel adder circuit, the other word being supplied by similar means. If both the 1 and 0 leads are connected to other circuits, the condition is known as "double lead transfer" of information.

An extra bit is included in an information word to indicate the sign of the binary number. A three-bit word such as +110 would be fed into the counter or register as 0110, where the first 0 (MSB) would indicate a positive number. A negative number would be 1110. Therefore, the circuits that handle signed words must have an extra FF to handle the sign bit.

A storage register and serial to parallel converter that does not use an associated counter is shown in figure 14-17. Delay lines are used in this instance to provide the conversion from serial to parallel. Each delay line introduces a delay equal to the input pulse spacing. Therefore, the first input pulse (the one on the left) arrives at A4 at the same instant that the last bit pulse is applied at A1. The input pulse spacing is the same as that of the clock pulses for serial form. Therefore the read pulse would be taken from the clock, but it would not be applied to the AND circuits before the last input pulse was applied to A1. With the exception of the delay line feature, the circuit is the same as the one in figure 14-17.

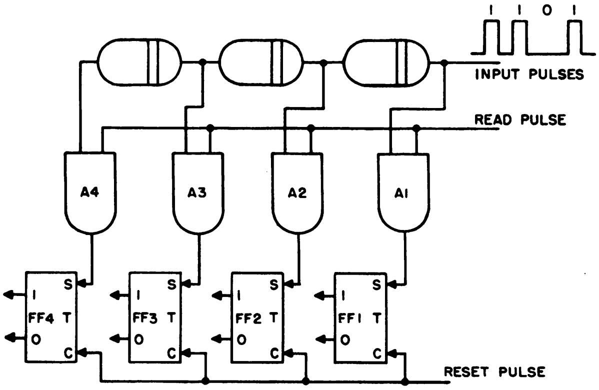

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Figure 14-17.—Storage register using delay lines.

Shift Register

A shift register is a storage register in which the stored number can be shifted left or right with a shift pulse. (See fig. 14-18.)

The shift pulses are applied continually, and they have the same spacing as the bits of the word. But since the FF would be upset if a shift pulse and a bit pulse occurred simultaneously, the shift pulse is applied midway between bit pulses. The FF's are so coupled that any particular one is set to a 1 state only if the preceding one was reset to 0 by the shift pulse. The delay lines (which may be RC circuits) have a delay that is only a small portion of the spacing between pulses. The operation of the shift register is discussed in the following paragraphs.

Assume that the binary word 1101 (decimal 13) is to be stored. The first 1 bit is applied and sets FF1 to 1. This does not affect FF2. A shift pulse then occurs that resets FF1 to 0; and FF2 receives, after a short delay, a pulse from FF1 that sets it to 1. Then the second 1 bit is applied to FF1, setting it to 1 again. Now

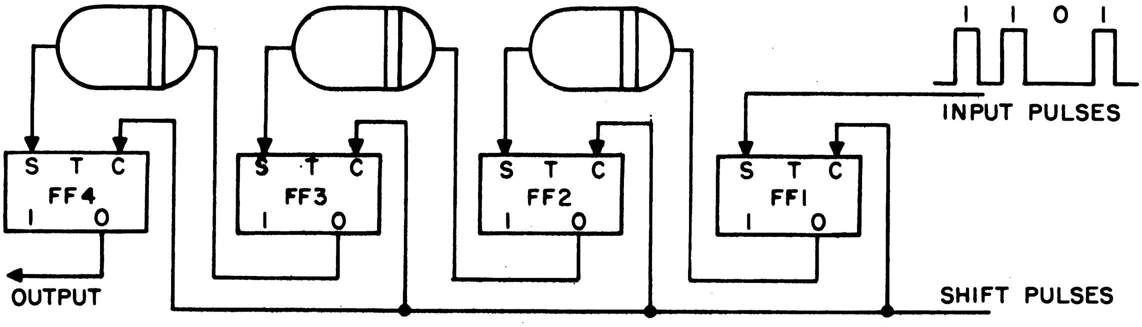

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Figure 14-18.—Shift register.

both FF1 and FF2 are set to 1; and another shift pulse occurs, resetting them to 0. Shortly thereafter, FF2 and FF3 are set to 1. The next bit in the word is a 0 and has no effect on FF1. The following shift pulse resets FF2 and FF3 to 0; later, FF3 and FF4 are set to 1. FF1 and FF2 now read 0. The last bit sets FF1 to 1. Shift pulses are stopped at this point, and binary word 1101 has been stored.

The application of four additional shift pulses causes the stored word to be read out the left side of the register. The contents can be read out to additional FF stages, to the memory unit, or to adder circuits. The output might also be returned to the input, through pulse reshaping amplifiers, to form a dynamic (circulating) type register.

If the register contains many more stages than there are bits in the stored word, the stored word can be shifted to the left and its changing value doubled by each successive shift. For example, if the word 1101 (decimal 13) is shifted to the left by 1 bit, the register will read 11010 (decimal 26). If 11010 is shifted to the left again, the register will read 110100 (decimal 52). Therefore, each left shift multiplies the register word by binary 10 (decimal 2). Note that the decimal point location in this particular register does not shift. In this case, it remains at the input terminal, or to the right of the last stored bit.

Additional stages must be switched into the right-hand side of the register before the word 1101 can be shifted to the right. Assume that 1101 is stored and it is desired to shift it to the right. The decimal point is fixed at the input terminal point. Now, additional FF's are switched into the right side of the register, and a shift pulse is applied. The register will now read 110.1 (decimal 6.5). Thus the stored word has been divided by binary 10. Another shift pulse would produce 11.01 (decimal 3.25).

Accumulator

Of the various types of registers found in an automatic digital computer, the type which is most important has the capacity to store a word, then receive additional words and sum the total. A register with these features is defined as an accumulator. It will most likely also incorporate left and right shifting features and be capable of dynamic operation. It must be able to provide this additional feature while handling the maximum computer word length.

Figure 14-19 presents a simplified block diagram of a serial arithmetic unit and indicates the importance of the accumulator. The accumulator can receive or send information to the memory unit; the stages of the shift register can be added to the accumulator to form a double length accumulator during multiplication and division; and the complement register can be complemented and its contents added to the contents of the accumulator. The importance of the relationship displayed by this block diagram will become clear during a discussion of adders and the computational processes.

ADDERS

Adders in digital computers use combinations of AND, OR, NOT, and INHIBITOR circuits to perform the functions of addition. When

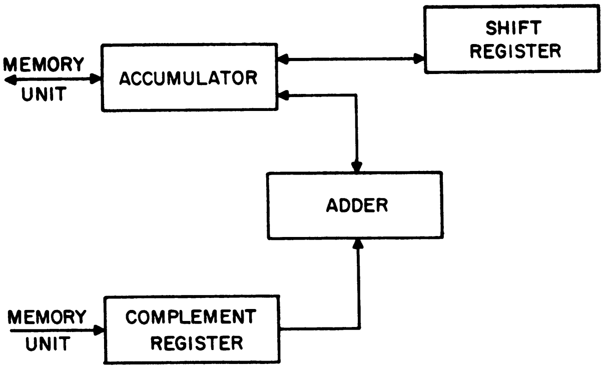

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Figure 14-19.—Simplified block diagram of a simple serial arithmetic unit.

adding numbers, it is often necessary to CARRY a number to the next column. For example,

$$\begin{array}{r} \textcircled{1} \\ 45 \\ +\,19 \\ \hline 64 \end{array}$$

It is the carry function of arithmetic (the 1 encircled) that necessitates complex circuits in computers. Were carries not needed, a simple OR circuit could easily add numbers, for it has an output pulse whenever pulses appear at both inputs.

A binary word appears as a train of pulses with spaces to indicate 0's. In an adder, a pulse train applied to one input will be added to a pulse train applied to another input.

Binary addition is performed as follows when a carry is involved:

$$\begin{array}{r} \textcircled{1} \\ 001 \\ 101 \\ \hline 110 \end{array}$$

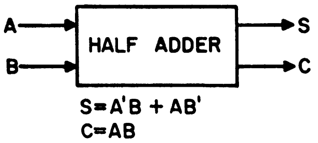
In the first column, a 1 is to be added to a 1—the sum is 0 with a 1 carry. The 1 carry is shown encircled over the second column; adding the 1 carry to the two 0's in the second column produces a sum of 1, with no carry; in the third column a 1 added to a 0 produces a sum of 1. Thus, 110 is the correct sum.

It has already been pointed out that a counter can total the number of pulses in a word and store the word temporarily. It was also mentioned that the accumulator is very flexible in this respect; it can receive several words, add them, shift them right or left, and store them. However, the counter and the accumulator are limited in the word lengths they can handle or store. A serial adder has no word length limitations; it is limited only by the storage capacity of the memory unit.

These adder units do not contain new kinds of circuits; they are made up of the basic logic circuits that have already been discussed.

Serial Adders

The half adder is the basic adder circuit for binary addition. It is called a half adder because it performs only the lowest order of addition—it has no input terminal for a carry. Remember, a carry (C) is generated when 1 and 1 are added to give a sum (S) of 0, producing a C of 1. Figure 14-20 is the block diagram and input/output table for a half adder.



INPUT		OUTPUT	
A	B	S	C
1	1	0	1
1	0	1	0
0	1	1	0
0	0	0	0

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Figure 14-20.—Half adder block diagram and input/output table.

Notice, in figure 14-20, that the S (sum) output is in the 1 state only when A and B are unlike. This is expressed by the equation $S = A'B + AB'$, where A' and B' have the same meaning as $\bar{A}$ and $\bar{B}$. This is the EXCLUSIVE OR function discussed earlier, and can be mechanized as shown in figure 14-21.

Assume that A = 11 and B = 101. The first two bits of each word are applied simultaneously and produce a 1 output from the OR and AND circuits, but the S output is 0 because of the inhibit action. The 1 from the AND circuit is the

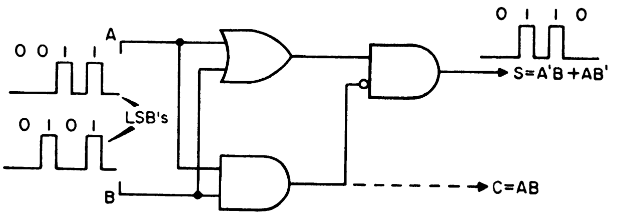

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Figure 14-21.—Half adder (EXCLUSIVE OR) circuit.

C output. The next set of bits, a 1 and a 0, produce an S output of 1. The last set of bits, a 0 and a 1, produce an S output of 1. Checking the S output, the result is seen to be 110, with a C output of 1. This could be considered a wrong answer; but, if the carry could be utilized during the addition process, the correct answer of 1000 would be produced.

To utilize the carry during the addition process, two half adders, a delay line, and an OR circuit (for isolation) can be employed as shown in figure 14-22. This combination is known as a full adder. Each half adder of figure 14-22 consists of an EXCLUSIVE OR circuit.

The first two 1 bits of A and B produce only a C1 carry of 1 from the first half adder, and S1 is 0. C1 is delayed by an amount equal to the bit spacing before being applied to the second half adder. The second set of A and B bits are a 1 and a 0, respectively. This results in an S1 of 1 and a C1 of 1 being applied to the second half adder, producing an S output of 0 and a C output of 1. This 1 of the C output is fed back, delayed, and applied to the second half adder. At the same time, an S1 output of 1 is produced in the first half adder and applied to the second half adder. This results in another 0 at the S output and a 1 at the C output. Now this C is delayed and applied to the second half adder again. A and B are 0 at this time, and the second half adder receives an S1 of 0. This causes the second half adder to produce an S output of 1 and a C output of 0. The result of the addition is now correct:

$$A = 11$$

$$B = 101$$

$$S = A + B = 1000$$

Note that this is strictly arithmetic addition of binary numbers 11 and 101, not Boolean algebra addition.

Parallel Adders

Parallel addition is used where computational speed is important or for adding binary coded

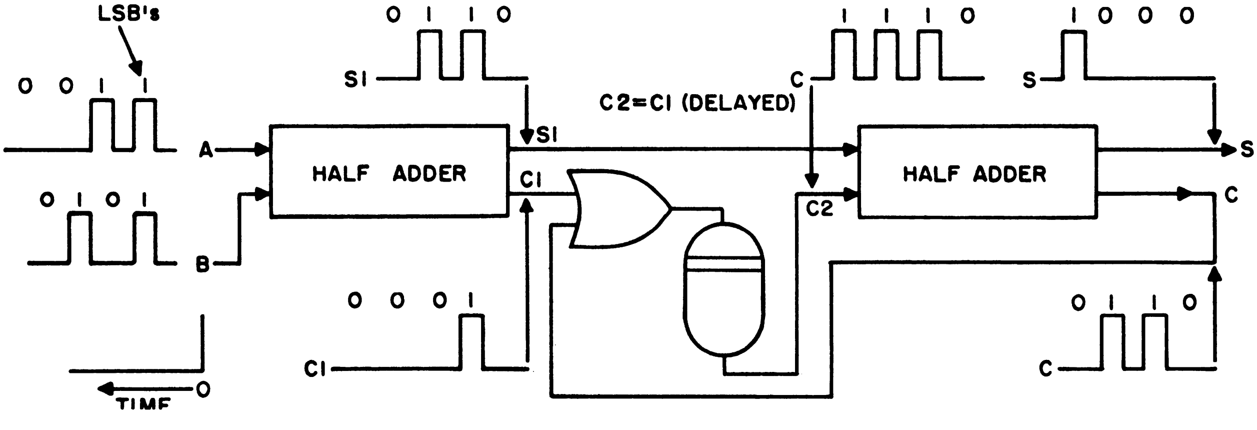

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Figure 14-22.—Full adder block diagram and bit trains.

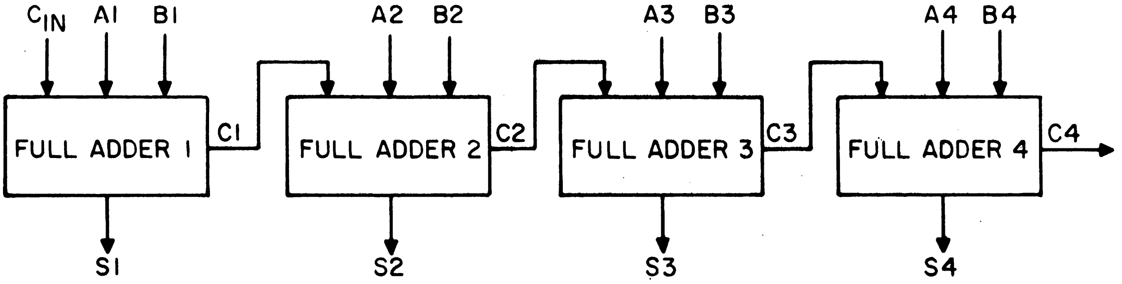

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Figure 14-23.—Parallel adder.

decimal (BCD) words. Figure 14-23 shows the block diagram of a parallel adder, which is nothing more than four full adders with parallel inputs and the carry applied serially between stages.

Assume that two decimal numbers, 3471 and 1318, are to be added as BCD numbers, using the 8421 code for conversion into BCD. The decimal 3471 would become

A1	A2	A3	A4
0011	0100	0111	0001

and 1318 would become

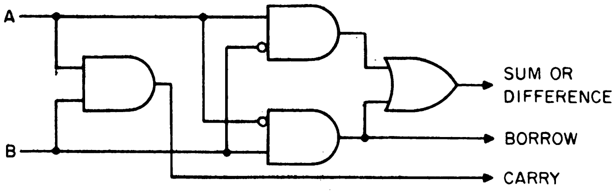
B1	B2	B3	B4
0001	0011	0001	1000

The bits in each group A1, B1, etc., are applied serially to the correspondingly designated terminals, but each group is applied simultaneously. The C_{in} comes from a previous adder, the C4 and the sums would be A or B inputs to a higher order adder if it were necessary to add three decimal numbers. This adder could also be used to add two four-bit pure binary words or for the parallel-bit addition of four serial words.

One point needs clarification. It was assumed that each partial carry was produced with no delay between bit input and carry output. This cannot be achieved in practice; therefore, the A and B inputs down the chain must be delayed enough to allow the respective carry to appear at the time the A and B inputs are applied down the chain.

Adder-Subtractor

An arrangement of logic circuits is possible that will perform either addition or subtraction. The half adder-subtractor form of such a group is shown in figure 14-24. It is composed of one AND gate, two INHIBITOR gates and one OR gate. A carry is generated by the AND circuit and used during addition. During subtraction of binary numbers a case occurs where there is a borrow of 1. This 1 can be borrowed from the output of one of the INHIBITOR circuits.



INPUTS		OUTPUTS			
A	B	SUM	DIFFERENCE	CARRY	BORROW
0	0	0	0	0	0
1	0	1	1	0	0
1	1	0	0	1	0
0	1	1	-1	0	1

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Figure 14-24.—Half adder-subtractor and input/output table for addition and subtraction.

Two half adder-subtractor circuits can be used to form a full adder-subtractor, with an additional OR circuit and a delay line having a delay equal to bit spacing in the words, as

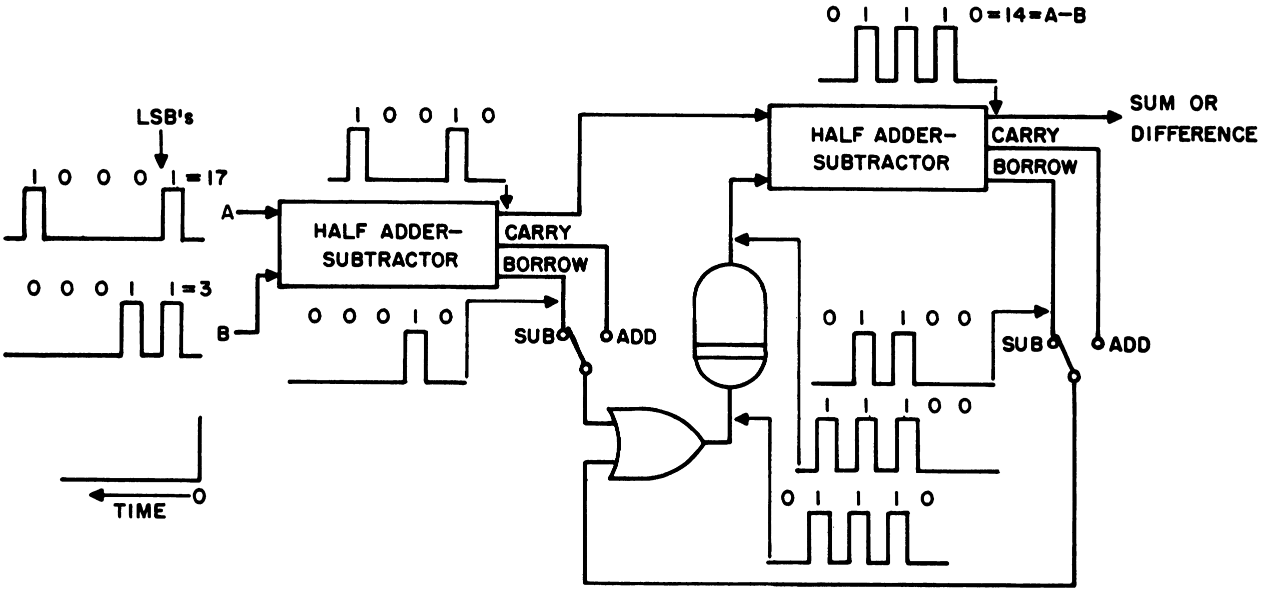

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Figure 14-25.—Full adder-subtractor, with waveforms for the subtraction of decimal 3 from decimal 17.

shown in figure 14-25. Addition uses the carry output of the first half adder and the feedback from the second one for application to the OR circuit. During subtraction, the borrow output of the first half adder-subtractor is applied, via the OR circuit and delay line, to the second half adder-subtractor, and the borrow from the second one is fed back to the first one.

MEMORY DEVICES

The kind of storage employed by an automatic digital computer is decisive in determining the form a computer may take. A computer's storage or memory is sometimes referred to simply as a store.

LEVELS OF STORAGE

Internal storage refers to storage which the programer, or coder, would normally use. It is located within the arithmetic unit or main storage, and is characterized by high speed and low capacity.

Secondary storage is cheaper and slower in access, but it has larger capacity. Access time could be as small as milliseconds for magnetic drums or up to minutes for magnetic tapes. Blocks of secondary storage are normally referred to the arithmetic unit as required, instead of direct reference to a specific storage location of a specific stored word.

External storage refers to punched cards, punched tapes and magnetic tapes stored in files or cabinets, which the computer does not have direct access to. External stored information is in a form which the computer can use, but it is physically separate from it.

The capacity of a store is measured by the amount of information in bits or (binary) decisions it can store. The storage capacity of a flip-flop is one bit. A register can store one word at a time, but an array or matrix of magnetic cores may store 10,000 words with fairly small bulk (each core may have an outside diameter of only 50 mils). The storage capacity of magnetic tapes used for external (slow access) storage may be essentially without limit.

Access time refers to the time required to write in and read out information from storage, including the time to communicate with the storage location. If destructive readout is employed, the "destroyed" information must be written back in before the cycle is complete.

Random access is said to occur if access to any storage location is independent of the storage address of the previous word. Access is said to be cyclic if the access time depends on the location of the previous word, as in the case of a rotating magnetic drum. (With a rotating magnetic drum, the addresses available at any given instant depend on the instantaneous drum position.)

Random access time for internal storage may be typically a few microseconds. but for secondary storage, milliseconds to minutes will be required.

Static or dynamic storage refers to whether the information changes location or not (when it is not being used). Examples of static storage devices are flip-flops and magnetic cores. Examples of dynamic memory devices are delay lines (with circulating pulse trains) and rotating magnetic drums.

Erasable storage is widely used in computers since it is essential in many instances to be able to store different words at different times at the same storage location. Examples of erasable storage include magnetic drums and magnetic tapes. Examples of nonerasable storage are punched cards and punched tapes.

Volatility relates to the loss or alteration of stored information due to an unintentional power loss. Regeneration or the periodic reinforcement of stored information, which is a common practice in dynamic storage, usually results in a volatile situation.

Serial (series) or parallel access refers to reading or writing one bit at a time or simultaneously. When all bits of a word are transferred in the same cycle, operation is said to be parallel. Only the smaller binary computers are entirely serial in storage access; on the other hand, very few computers use parallel storage systems altogether. Most use a series parallel arrangement. A parallel arrangement provides high speed at the cost of a great amount of additional equipment. On the other hand, a completely serial situation is usually too slow.

MAGNETIC DRUMS

A magnetic drum is the cheapest form of internal storage for a small computer; the data stored on the drum is erasable but nonvolatile (not lost when the power is turned off).

The magnetic surface of a rapidly rotating drum is a very economical main store for a small computer. Rotating at a speed of several thousand rpm, a track spacing of several tracks per inch may be obtained. Each track has the capacity of storing many bits, normally in the thousands, depending on the drum size, speed, and so forth. Heads for writing on or reading from the drum are mounted so that the drum rotates in close proximity to them.

Access to data stored on the drum depends on the rotational speed and the location of the particular data desired. When the desired data has just passed the head, access time is maximum—one revolution. If the desired data is under the head, access time is nearly 0. Thus, for the general case, average-access time is half of a drum revolution, but by "optimum programing" this can be reduced.

Magnetic drums vary greatly in capacity and operating speed. Speeds of 3,000 to 17,000 rpm and diameters of 4 to 12 inches result in average access times of 2 to 10 milliseconds.

MAGNETIC DISK

The magnetic disk is similar to a phonograph record except that the tracks are circular instead of spiral. The spacing of the recording heads is maintained by an "air bearing." A very high storage capacity is characteristic of this type of storage. Its low mechanical inertia makes it appealing for airborne applications. Disk storage has been built with 100 concentric tracks on each side of each disk.

MAGNETIC TAPE

Perhaps the most familiar type of storage to the Navy technician is magnetic tape. The materials used may be the same as those used for audio recording, except that very high quality tape is required to avoid missing an occasional bit.

Seven channel tape is usually one-half inch wide. Its recording density is normally from 100 to more than 500 characters per inch of tape. Thus a 2,400-foot roll can store about 3 to 16 million characters. This is less than the apparent maximum because the gap between recorded sections of tape may be from 1/2 to 2 1/2 inches. Obviously, the tape must be brought up to speed before reading or writing is begun. A 2,400-foot tape with 200 characters per inch holds as much data as 25,000 cards, each 80 columns wide. Tape speed may be as high as 240 inches per second.

Under ordinary operating conditions, magnetic tape is usable up to 50,000 times; data on a used tape may, of course, be transferred to a new tape. Temperature and humidity variations may cause the oxide surfaces to crack, and dust may cause a signal to be missed. Oil or moisture from manual handling may encourage the collection of dust.

MAGNETIC CORES

Large computers employ many small toroidal (ring or doughnut shaped) cores made of ferrites, each of which can store one bit of information by becoming magnetized. The magnetizing force required is modest, since a single conductor passed through the core will suffice to perform the function of a winding. An array of such cores, typically each only about one-twentieth of an inch in outside diameter, was mentioned previously.

By arranging these cores in a rectangular matrix or array, very short access times are common because parallel access is practical with the use of modern high speed semiconductor switches. Access times of less than 10 microseconds are practical and commonplace.

By coincident current techniques, any single core may be selectively read in or out. That is, by passing a current through both the horizontal wire and the vertical wire which pass through a given core, the two fluxes may be made to add and to exceed the threshold value necessary for switching the selected core.

INPUT AND OUTPUT DEVICES

An analog device yields an output in the form of a varying voltage, current, resistance, or mechanical shaft rotation. This form of output is unusable as an input to a digital computer. Since the majority of military indicating devices are of the analog type, their outputs must be converted to be used as inputs for the digital computers.

INPUT DEVICES

An input device is considered to be any device which yields an output which is usable for the particular computer it feeds. The devices which will be discussed are referred to as converters or encoders because they convert analog information into digital information.

V-Scan Converter

The V-scan converter continuously converts a changing mechanical position (analog information) into pulses (binary information) with an accuracy of plus or minus one bit (binary digit).

The basic method of converting a mechanical position into a binary code involves an arrangement of brushes and contacts. The mechanical movement positions the brushes relative to the contacts. The conducting contacts contain a voltage level which represents a binary 1 and the insulating contacts contain no voltage which represent a binary 0. The contact arrangement necessary to produce a natural binary code ranging from 0 to 15 is illustrated in figure 14-26.

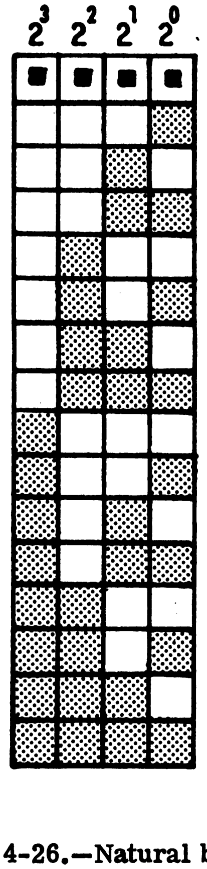

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Figure 14-26.—Natural binary code contact arrangement.

NOTE: For the purpose of discussion, consider the contact arrangement in figure 14-26 as being attached on the side of a tank containing a liquid. The brushes are controlled by the level of the float which varies with the level of the liquid in the tank. Notice that, as shown, when the brushes move downward, a binary indication of the amount of liquid expended is indicated. The dark areas are conducting contacts and the light areas are insulating contacts. The four squares at the top of the contact arrangements represent four in-line brushes. The position of the in-line brushes, as shown, indicate a binary 0000 or zero. The analog output moves the brushes down the contacts to indicate any binary number from 0000 (zero) to 1111 (fifteen).

Unfortunately, there is an ambiguity associated with the use of the in-line brushes and the natural binary code. This problem arises at any point where two or more brushes are required to switch at the same moment from one type of contact to the other; that is, from conducting to insulating or from insulating to conducting.

Figure 14-27 shows a portion of a four-bit binary coding plate and reveals the exact nature of the problem. Note that the brush positions that are indicated by x's are reading a 6 (0110). At this instant the brushes are obviously providing the correct reading. Examination of the next position of the brushes, indicated by y's, however, reveals ambiguous readings. For this example, the brush position is at the switching point from 7 (0111) to 8 (1000). The brush in the 2^3 column is making contact with the conducting material, while brushes in the 2^0, 2^1, and 2^2 columns are still making contact with the conducting material. The output from the brushes at this time is 15 (1111), which should not occur when moving from 7 (0111) to 8 (1000). This produces an erroneous reading. Note that erroneous readings are also obtainable at the 9 to 10 switching point and at the 11 to 12 switching point.

Obviously, the possibility of reading a 15 when it should actually be switching from 7 to 8 (or reading 11 when it should be switching from 9 to 10, or of reading any of the other ambiguous numbers that may be produced) makes it impossible to read instantaneous values with any high degree of certainty. The major factors in determining the accuracy of the natural binary-coded converter are the positioning of the contacts, the positioning of the brushes, the size of the contacts, and the thickness of the brushes. The perfect converter, in order to preclude ambiguities, would have each contact exactly in its required position, all brushes in a straight line perpendicular to the direction of movement, all contacts exactly the same size, and the brushes infinitesimally narrow and exactly uniform. Meeting the prestated requirements for a perfect converter is a physical impossibility.

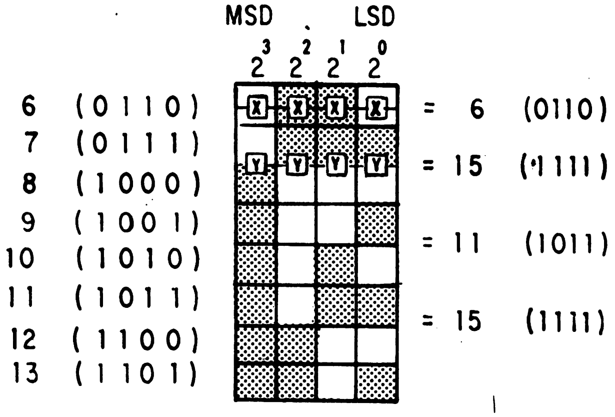

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Figure 14-27.—Ambiguity with the natural binary code.

The V-scan converter employs a method of conversion whereby the physical requirements allow almost perfect conversion. This is accomplished by the use of a double brush (except for the 2^0 column brush) system. The particular relationship between the brushes is predetermined. The direction of movement to be used when describing one set of brushes as leading and one set of brushes as lagging is determined by the design of the grid. In figure 14-28 the direction which will determine the leading or lagging brushes is downward. This direction must be used regardless of whether the float is causing the brushes to move downward or upward. This may occur when filling or emptying the tank.

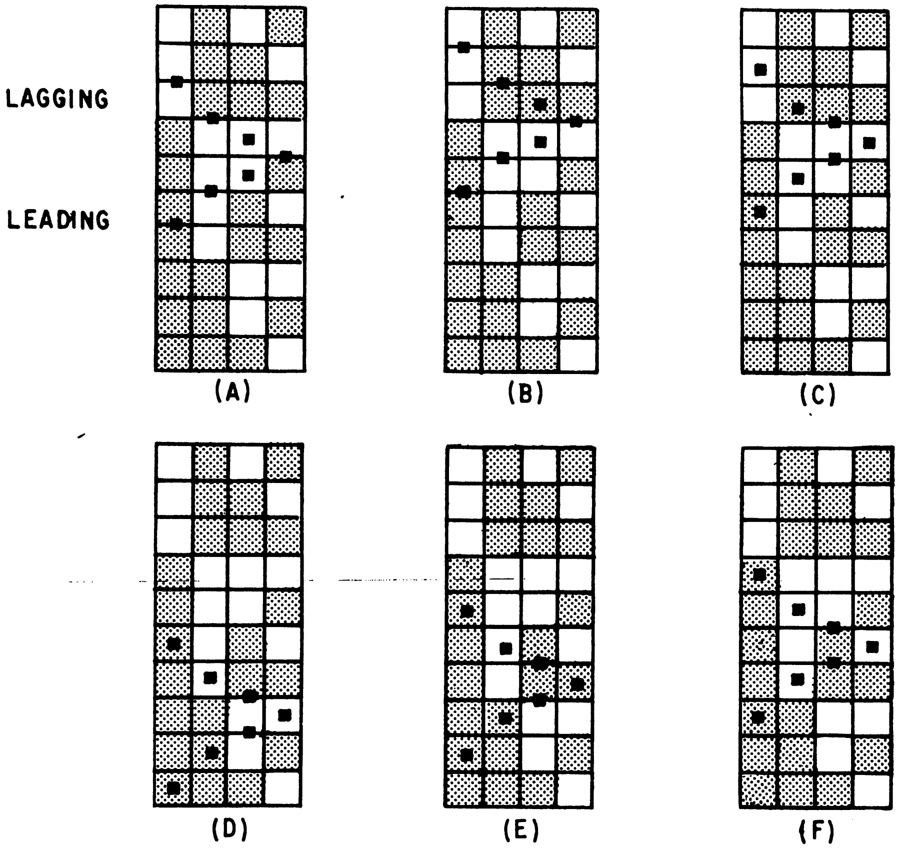
When reading the brush positions from right to left, two rules are followed:

1. If a bit is read as a one (electrical contacts touching) in a place value column, the next larger place value column is read on the lagging brush.

2. If a bit is read as a zero (nonconducting contact) in a place value column, the next larger place value column is read on the leading brush.

The determination of whether a leading or lagging brush is used at any particular time is a design function of this converter and will not be discussed.

Since the least significant digit (LSD) column has but one brush, it will always be the



AQ.197

Figure 14-28.—Natural binary code contact arrangement showing V-scan brushes.

reference. As shown in each section of figure 14-28, there are some brushes that are touching conducting and nonconducting segments at the same time. By applying the previously stated rules, figure 14-28(A) is read as follows:

Column 1: This is our reference brush and since it is conducting a binary 1 is read.

Column 2: Read the lagging brush position because column 1 brush was conducting. The lagging brush position indicates a zero.

Column 3: Read the leading brush position because column 2 brush was not conducting; therefore, a zero is read for column 3.

Column 4: Read the leading brush position which indicates a zero. Therefore, figure 14-28(A) is indicating $1001_{(2)}$ or $9_{(10)}$.

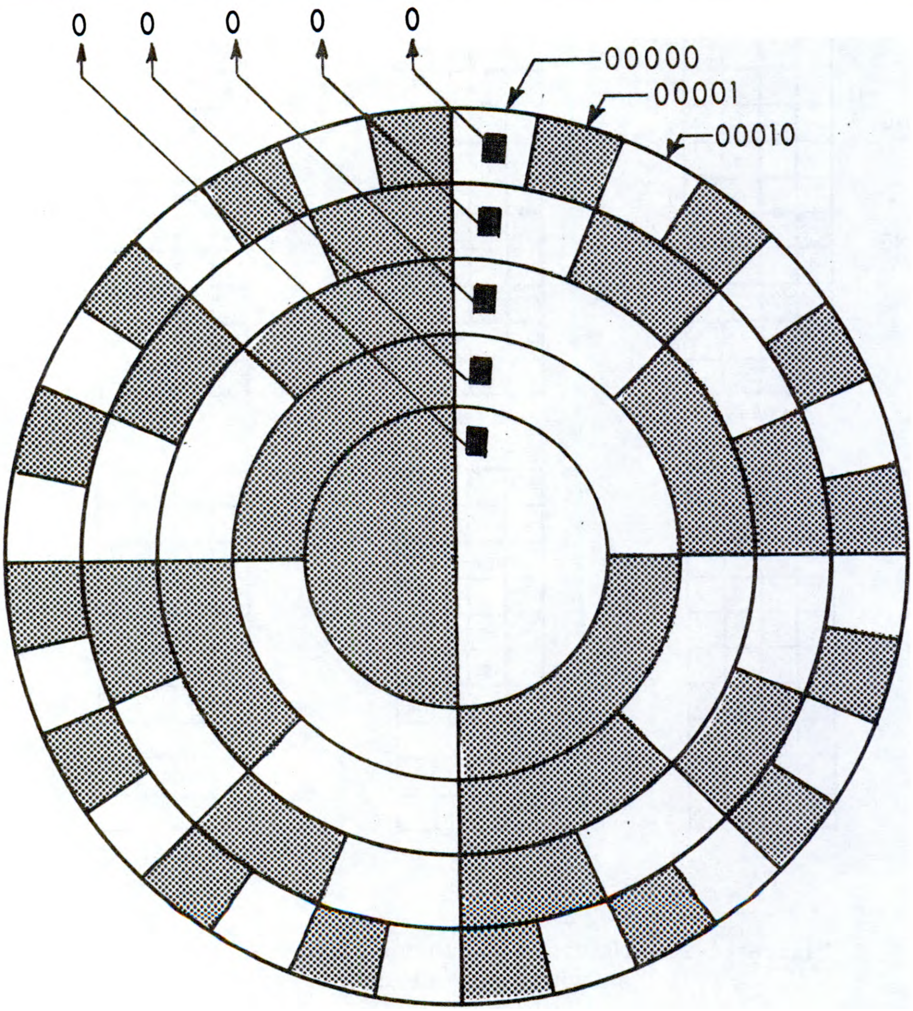
The following sections of figure 14-28 indicate:

Figure 14-28(B) - $0111_{(2)}$ or $7_{(10)}$
Figure 14-28(C) - $1000_{(2)}$ or $8_{(10)}$
Figure 14-28(D) - $1100_{(2)}$ or $12_{(10)}$
Figure 14-28(E) - $1011_{(2)}$ or $11_{(10)}$
Figure 14-28(F) - $1010_{(2)}$ or $10_{(10)}$

BINARY WHEEL.—The binary wheel is a basic application of converting shaft rotation (analog) to binary (digital) information.

The binary wheel is a plane comprised of concentric circles, with each ring divided into twice as many sectors as the adjoining inner ring. A close examination of figure 14-29 will show that it is really the previous rectangular set of contacts (fig. 14-27), set up in concentric rings. If the brushes are located in a straight line, as shown in figure 14-29, the same difficulty of erroneous indications will be present as the brushes move around the circles.

By installing dual brushes in all rings except the outer (least significant digit) ring, as shown in figure 14-30 and properly placing the brushes,



AQ.198

Figure 14-29.—Simple five-bit shaft encoder.

the erroneous readings may be eliminated. The number indications are read as previously indicated for the V-scan readings. The direction of rotation of the disk determines which set of brushes will be leading or lagging—in this case, clockwise.

Shaft Position Encoder

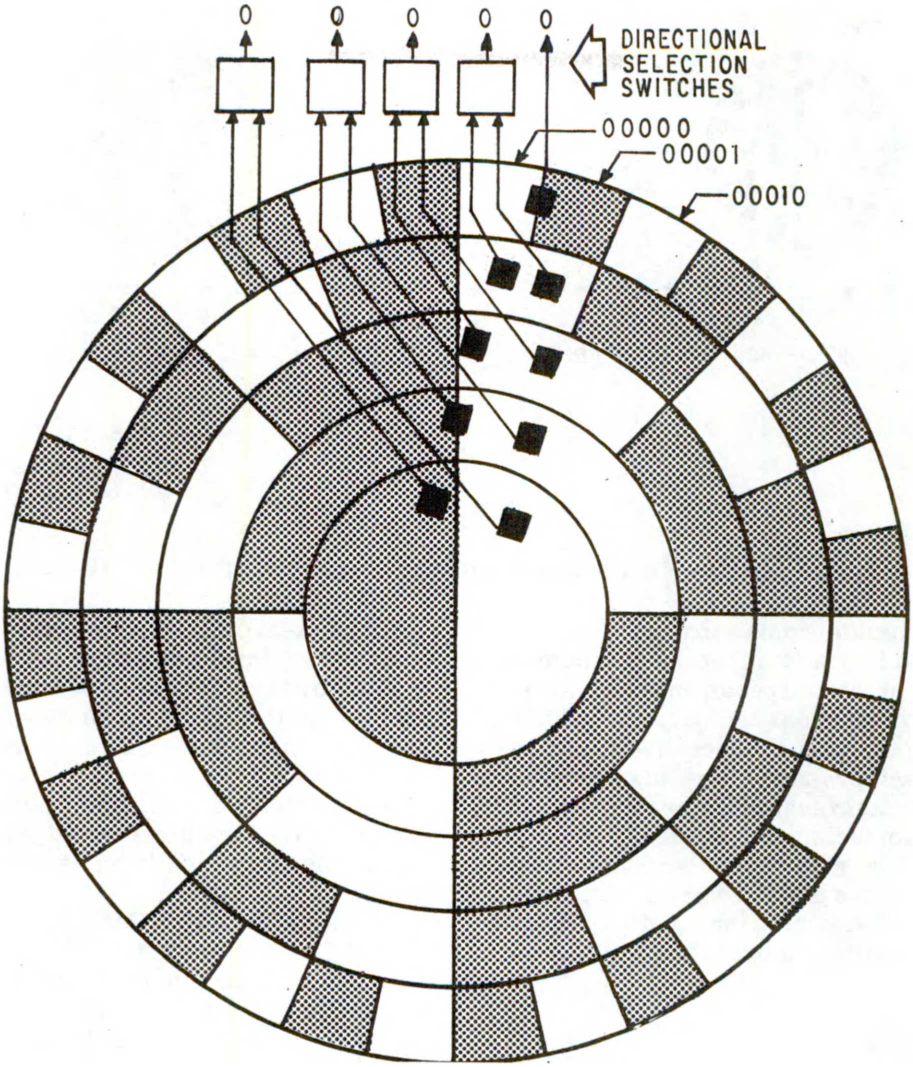
Shaft position encoders are electromechanical devices used to generate a binary number representing the angular position of an attached shaft. This encoder shaft is usually connected to the shaft of a motor of potentiometer via a gear train.

Figure 14-31 illustrates the type of shaft position encoders used in the Ballistic Computer Set ASQ-61A, installed in the A-6A aircraft. The shaft position encoder used in this system is discussed more thoroughly later in the chapter under INPUT UNITS.

Binary Gray Coded Grid

Figure 14-32 shows a grid (coded in the Gray code) with five brushes. The shaded blocks indicate 1 binary, and the blank blocks indicate 0 binary. This is the same as previously used. Notice that as the brushes (x) move down the grid, only one brush will change its state (conducting to nonconducting or nonconducting to conducting) as the number is increased by one.

The brushes are shown to be indicating two in Gray binary; and as they move to 3 Gray



AQ.199

Figure 14-30.—Five-bit V-scan encoder.

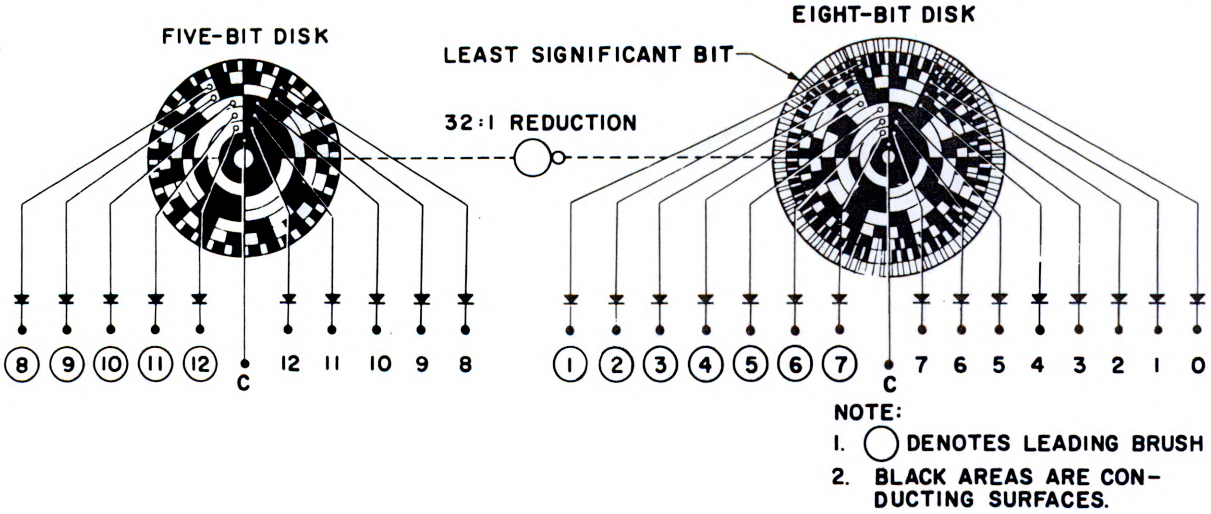
binary, only one brush changed state. In figure 14-27 the movement from 7 to 8 caused an erroneous reading. Notice that as the brushes (y) shown in figure 14-32 move from 7 to 8, an erroneous reading does not occur because only one brush changed state.

BINARY GRAY CODED WHEEL.—Figure 14-33 shows the binary Gray coded wheel in which angular position of the brushes is represented by a Gray coded number. In changing from one number to the next, only one brush changes state. Notice that one set of brushes allows indications in sequential steps without ambiguous readings when moving from one number to the next.

In figure 14-33 the brush reading line shows the reading to be 01001 in Gray code. This indication could represent bearing, speed, direction, or any of many analog positions.

Brush Encoder Problems

The disadvantages of brush type encoders are early and frequent failures caused by excessive brush and disk wear, frequent miscounting, critical brush alinement, and low operating speeds. Brushes are susceptible to vibration and acceleration forces that can cause intermittent contact and shifts in brush position. High rotational speeds cause wear of the



NOTE:
1. ○ DENOTES LEADING BRUSH
2. BLACK AREAS ARE CONDUCTING SURFACES.

AQ.200

Figure 14-31.—Shaft position encoder disks, placement of brushes.

brushes and particle contamination of the code disk, which lead to a diminution of accuracy. Brush bounce at high speeds may be severe, resulting in extraneous pulse outputs. Although a compromise may be reached by an increase in brush-contact pressure, this also increases the load torque, aggravates the problem of wear of the brush contacts, and reduces life of the code wheel. The results are encoders which are unreliable, have a short useful life, require frequent and costly maintenance and/or replacement, and are limited in operating speed.

Electrical Converters

LINEAR POTENTIOMETER.—A potentiometer may be used with its two ends connected to fixed reference potentials. The angular position of the slider may be represented by the unloaded voltage at the slider. Any variation in the reference voltage, or any current in the sensed voltage, can introduce errors into the reading. The voltage can be used directly (analog), or it may be supplied as a scaled voltage to the converter. For digital applications, a tapped rather than continuous potentiometer may be used, with the output then encoded to binary form for input to the computer.

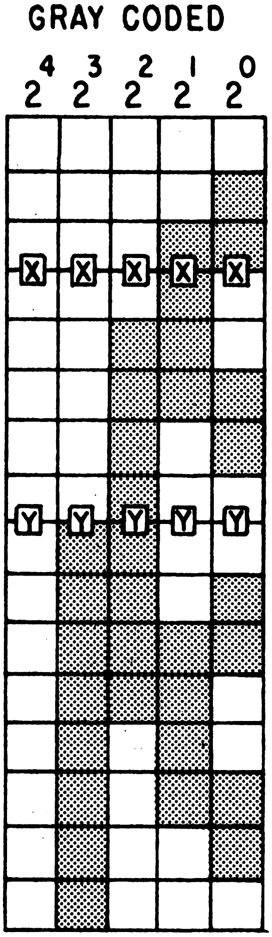
VOLTAGE TO NUMBER CONVERSION.—Electrical analogies (analogs) of most measurable quantities have been developed, with most instrumentation presenting its output as a scaled voltage (1 volt = 100 miles, 1 volt = 1,500 gallons, etc.). It is necessary to convert both the voltage level and the scale factor into terms usable by the computer. It is not always necessary that the scale factor be inserted, as long as the computer has it stored at a unique address.

Examples of voltage to number converters are the digital voltmeter and the self-centering potentiometer used in angle to number conversion.

VOLTAGE TO TIME TO NUMBER CONVERSION.—A converter of the voltage to time to number type, in its simplest form, is very useful in scaled systems. The converter may require clock pulses, a linear sawtooth of voltage (ramp), a voltage comparison circuit, and a voltage that is to be measured.

Digital conversion is provided by starting a digital counter that has been synchronized with the sweep, and stopping it when the sweep voltage and the unknown voltage are equal. The clock pulses are counted, and the voltage change per unit time ($\Delta E/t$) factor is applied, so that the output reading is converted into a number. There is one counted output for each sweep as long as the unknown voltage is within the calibrated range of the sawtooth.

Accuracy of this system is limited by the slope of the sawtooth, by the accuracy of the timing system, and by the precision of the voltage comparison system. Making the same measurement concurrently (using two or more converters) and averaging the results decrease the inaccuracies of the system.



GRAY	BINARY	DECIMAL
00000	0 0 0 0 0	0
00001	0 0 0 0 1	1
00011	0 0 0 1 0	2
00010	0 0 0 1 1	3
00110	0 0 1 0 0	4
00111	0 0 1 0 1	5
00101	0 0 1 1 0	6
00100	0 0 1 1 1	7
01100	0 1 0 0 0	8
01101	0 1 0 0 1	9
01111	0 1 0 1 0	10
01110	0 1 0 1 1	11
01010	0 1 1 0 0	12
01011	0 1 1 0 1	13
01001	0 1 1 1 0	14
01000	0 1 1 1 1	15

AQ.201

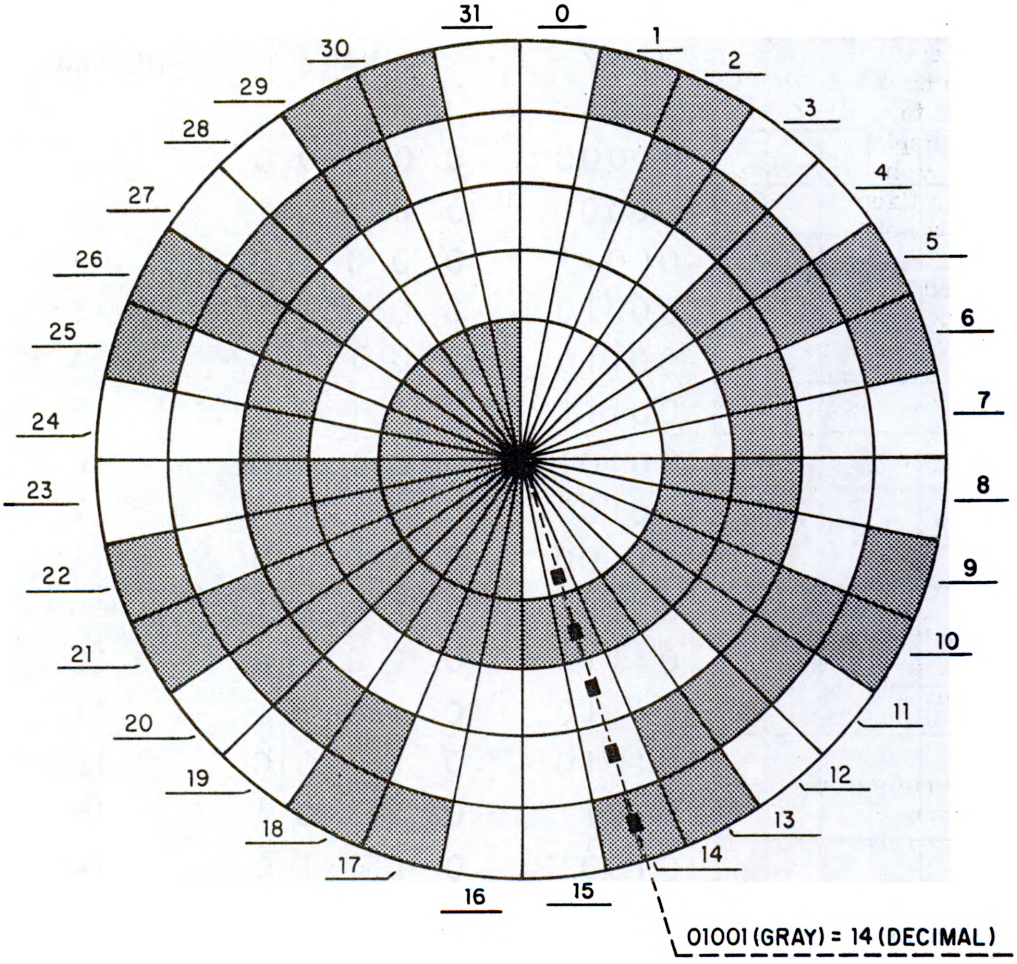
Figure 14-32.—Binary Gray coded grid.

The system indicates an instantaneous value; nothing is shown concerning the behavior of the input voltage before or after its intersection with the sawtooth. The sawtooth need not be linear, provided that its voltage as a function of time is known and used in the calculation.

SELECTIVELY ADD-SUBTRACT SYSTEM.— The operating principle of this system is the same as that of an equal arm balance, where an unknown weight in one pan is balanced by selectively adding or subtracting known weights in the other pan. The limit of accuracy, disregarding friction, is ±1/2 the smallest balance weight available. Similarly, a voltage balance analog system, selectively adding or subtracting, scaled resistors until balance is obtained, may be used. The advantage of this system is that the voltage may be larger or smaller than the reference voltage. A simple example is a balanced bridge with binary adjustments. The system may start either from a fixed point or from the last used point, with switching automatically sequenced and controlled by the computer.

Optical Encoders

In optical encoders, there are no contacting surfaces other than bearings. Photocells are used to detect light from a light source through a code disk which has alternately opaque and transparent segments. Electronic amplifying, discriminator, and logic circuitry is required to obtain the desired digital output. Continuous



AQ.202

Figure 14-33.—Binary Gray coded wheel.

low-voltage d-c tungsten lamps are usually used as the light source, which has a predicted life of over 10,000 hours. The mean-time-between-failure (MTBF) of optical encoders is at least 10 times greater than that of comparable brush encoders.

OUTPUT DEVICES

Input and output devices are similar in operation but perform opposite functions. It is through the use of these devices that the computer is able to communicate.

Output information is also made available in three types: human information, such as codes or symbols presented on a cathode-ray screen which are used by the operator to answer questions or make decisions; information which operates a control device such as a level, aileron, or actuator; or information which is stored in a machine language or human language, on tapes, printed media.

Wheel Displays

Any one of the angle to number converters previously described can be connected as an output device, either to furnish an angle signal or display (pointer or servo signal) or to mechanically position a particular symbol on a wheel display. The symbol to be displayed can be any arbitrary number, letter, word, or other symbol selected by the designer.

The wheel can be positioned by a servomotor, by a step counting switch, by a digital to analog converter coupled with a motor, etc. The only limitation on the positioning system is that it must be able to drive the wheel until the correct symbol is displayed.

The display may be generated by wheels geared together in a fixed ratio (as in an odometer) or with each wheel individually driven and positioned. A disadvantage of the second system is the increased space required to accommodate the separate drive mechanisms. The number of symbols to be displayed is limited by the size of the wheel and by the number of discrete positions that can be selected.

Practically any encoder can be used as a decoder (digital-to-analog converter) either directly or by positioning it with a null-seeking driver.

Lights

Each individual light may be considered as the equivalent of a binary stage: ON—true or one; OFF—false or zero. Lights are used to display such discrete data as failsafe, on-off, and warning. They may be used in groups and in conjunction with ring counters to form binary to decimal conversion displays. Each individual light is sequenced and illuminates the appropriate digit when switched on by the counters. (See fig. 14-34(A).)

MULTIFILAMENT LIGHTS.—These lights may display numbers, letters, symbols, or combinations of these. Filaments may "edge light" lucite cards to illuminate engraved symbols, or may actually be shaped in the form of the symbol and glow when switched on. (See figure 14-34(B) and (C).)

Lights require appreciable current—greater than that which is normally available directly from the computing circuits. Therefore, a buffer or amplifier stage is usually required to furnish the additional current. Since a single display illuminates multiple symbols and requires at least one terminal for each, it may require its own counter circuits to convert from binary code to the display code, or it may share a common converter with several other circuits. On the other hand, the individual filaments may be prewired to a printed circuit board, and the appropriate display selected and switched by computer circuitry.

The value or quantity being measured may be represented by a positioned display of multiple filament lights. The digital voltmeter is a fairly common example of the use of these lights.

TAPE DISPLAYS.—Rather than increasing the size of the wheel to increase positional accuracy and to increase the number of symbols that can be displayed, tape displays are frequently used. The small wheel simply acts as an idler wheel for a tape bearing a large group of symbols. This system has several advantages, but the primary advantage is that it provides a clearly legible (precise) display in a minimum of space.

Many "games" can be played with the tape system to increase packing density. The digits of several tapes may be alined and projected. The depths of the tapes can be staggered,

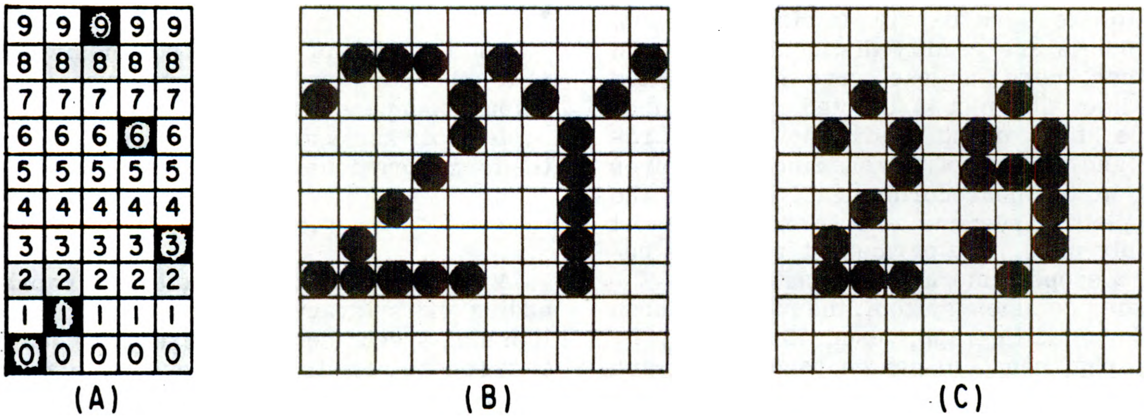
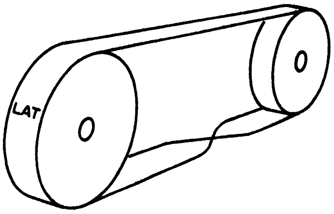


Figure 14-34.—Light displays.

making it possible to package the drive mechanism in line with the tapes. The tape can be coded and may actually carry the control wiring for its own positional drive motor, simplifying external wiring.

The tape (if of a sufficient free length-to-width ratio) may be formed into a "Mobius band," permitting doubling the number of symbols on a band of given length and/or permitting staggering the symbols so they can be trans-illuminated (projected). (See fig. 14-35.)



AQ.554
Figure 14-35.—Tape display.

Plotters

Digital computers frequently use plotters to represent two properties of a variable: latitude and longitude, altitude and bearing, amplitude and time, etc. Most digital plotters are simply plotters which already exist for analog systems, with the computer merely furnishing signals (through digital to analog converters) as the input signals.

The plotter may be either the recording or the nonrecording type. The digital data displayed (plotted) are a series of discrete values. If the points are readily distinguishable from each other, more than one curve may be plotted at one time. The plot is affected by the number and type of recording heads, the speed of response, and the rate of travel. Since it requires no motion, the nonrecording CRT is one of the fastest plotting systems, and is one of the most commonly used. If a permanent record is required, a scope camera can be installed.

Another common system, the moving ribbon recording oscillograph, used Xerography or photography, pencil or pen on regular or graph paper, pressure-sensitive paper, electrosensitive paper, or waxed paper. The motion of the paper generates one dimension (generally the time, control, or X coordinate), while the lateral motion of the recording device generates the second dimension.

In other systems the recording device is moved in both the X and the Y coordinates over a stationary surface. This is the principle of the oscilloscope and the DRT table. A direct digital control divides the X-Y plane into discrete points, determined by the matrix. A buffer stage may be necessary between the measured voltage and the converter, in order to insure sufficient power to drive the mechanical device. The buffer may be gated to accept a signal only upon command from the computer, or it may be gated continuously.

Selection of the type plotter for use is frequently made on the basis of the input signal. Slowly varying signals may use a mechanical device, while rapidly varying signals may require a more rapid system. Figure 14-36 illustrates a display of Cartesian coordinates by means of individual lights.

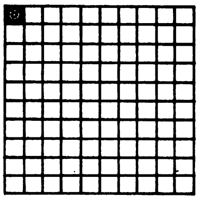


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Figure 14-36.—Cartesian coordinates display.

Operational Circuits

Another set of outputs commonly used in military computers are the operational outputs, actual command and control signals to other systems or subsystems. They may be in any of the forms previously discussed.

PROGRAMING

A modern digital computer is capable of adding and subtracting almost indefinitely with lightning speed. Some can also make decisions, based on the results of the previous calculations. However, despite these capabilities, the computer cannot automatically perform its functions by itself. Each step of the problem that the computer is to solve must be worked out in advance by a "programer." The programer is someone who decides how the problem should be worked by the computer and then writes the program which outlines the sequence of operational steps. These instructions must be placed in the computer, and made to activate the internal circuits so that the computer will process for solutions to problems.

The programer may not be concerned with the actual answer to the problem, but only that an answer is produced and placed in the memory unit at a specified address. The computer may be instructed to perform the same operation over and over; and if any of the data changes, the solution will also change. The solution to one problem is often used in making other calculations required in the overall operation.

The programer for a computer does not necessarily need to know the mechanical or electronic theory of a computer, but he does need to know its maximum capabilities.

The switching or routing system of signals in computers can be compared to a huge railroad yard where many trains are being routed through a maze of tracks. All the trains are controlled from a central point and move as directed by the controller. A train is formed by directing an engine to move through the maze of tracks in the yard, picking up one or more cars at designated points. The completed train then moves out of the yard as an integral unit.

The paths followed in forming the train were predetermined and directed in sequence by the controller. In a similar manner, the control unit of a computer is the controlling device that does the switching, and the courses taken by the binary bits resemble the tracks of the yard. In the output of the computer, the completed data is analogous to the train.

Technically programing is only one part of preparing a problem for solution by a computer. There are actually four major steps, as shown in figure 14-37. These are numerical analysis, planning the sequence of operations (programing), coding, and checking. These jobs are frequently referred to collectively as "programing."

NUMERICAL ANALYSIS

Numerical analysis is the definition, in proper mathematical terms, of the problem to be solved. It is the science of reducing real problems into terms, quantities, and equations that a digital computer can accept. In all but the simplest problems, extensive numerical analysis may be required before the program can be written. How does one represent these terms, quantities, and equations? Numerical tricks, approximations, and even arbitrary values must sometimes be used in order to translate these concepts into the discrete, numerical values required by the computer.

PROGRAM PREPARATION

Normally, problems are too long and too complex to encode directly from the mathematical analysis. Programing provides the shorthand, or guide, which makes it possible to translate the mathematical operations into the step by step operations required by the specific computer to be used. Programing is primarily the task of drawing flow charts, or block diagrams, and planning memory allocations.

A flow chart (illustrated in (B) of fig. 14-37) is essentially an annotated block diagram and is an organizational convenience. In addition to depicting the overall system logic, it shows the sequence of logic operations, the result of each choice, and the time and entrance point of all new data.

Although it is intended principally as an aid in writing the computer code, the flow chart is also an excellent troubleshooting and testing device. It uses symbols to describe the various functions to be performed, to indicate a logical choice or optional sequence, and to show when a sequence is changed by new or modifying instructions. Additional symbols and conventions are generally used to simplify the diagram and to make it a more complete instrument for aiding the man writing the code. These symbols are not standard, but they are usually consistent in a given set of charts. Their main purpose is to transfer information from the designer to the coder or other users of the computer.

CODING

Coding is the step by step transformation of the problem, as mapped out by the flow chart, into a final program written in the language of a particular computer. Coding is essentially a precise bookkeeping operation; each address,

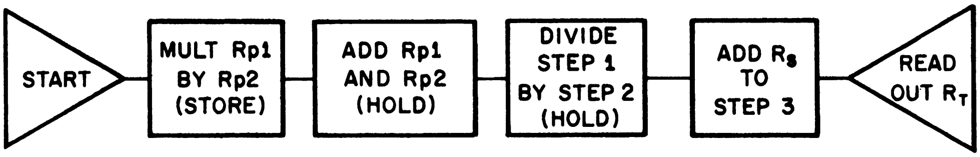
A NUMERICAL ANALYSIS

PROBLEM: DETERMINE TOTAL CIRCUIT RESISTANCE.

$$R_T = \frac{Rp1 \times Rp2}{Rp1 + Rp2} + R_s$$

Rp1 AND Rp2 = PARALLEL RESISTORS
R_s --------- = SERIES RESISTORS

B PROGRAMING



C CODING

INST. NO.	
1	MULTIPLY Rp1 BY Rp2 (STORE)
2	ADD Rp1 AND Rp2 (HOLD)
3	DIVIDE STEP 1 BY STEP 2 (HOLD)
4	ADD R_s TO STEP 3
5	READ OUT R_T

D CHECKING

INST. NO.	
1	$Rp1 \times Rp2$
2	$Rp1 + Rp2$
3	$\frac{Rp1 \times Rp2}{Rp1 + Rp2}$
4	$\frac{Rp1 \times Rp2}{Rp1 + Rp2} + R_s$

$$R_T = \frac{Rp1 \times Rp2}{Rp1 + Rp2} + R_s$$

AQ.556

Figure 14-37.—A simple four-step program for a digital computer.

each digit, and every single command must be correct.

The coder, unlike the man who writes the flow chart, needs little knowledge of mathematics; he does not even need to understand computers. The only absolute requirement is that he adhere inflexibly to the rules as established by the design of the computer. Generally, in transferring from one type or model computer to another, the coder must learn a new set of rules, a new computer language, or a new code.

CHECKING

Checking, or verifying, is the final step in the preparation of a particular computer problem. It is frequently performed automatically. The sole purpose of this step is to insure that the coder has made no errors. The coded program may be stored internally or externally. Storage may be either semipermanent or permanent, depending upon the purpose and application of the computer.

CHAPTER 15

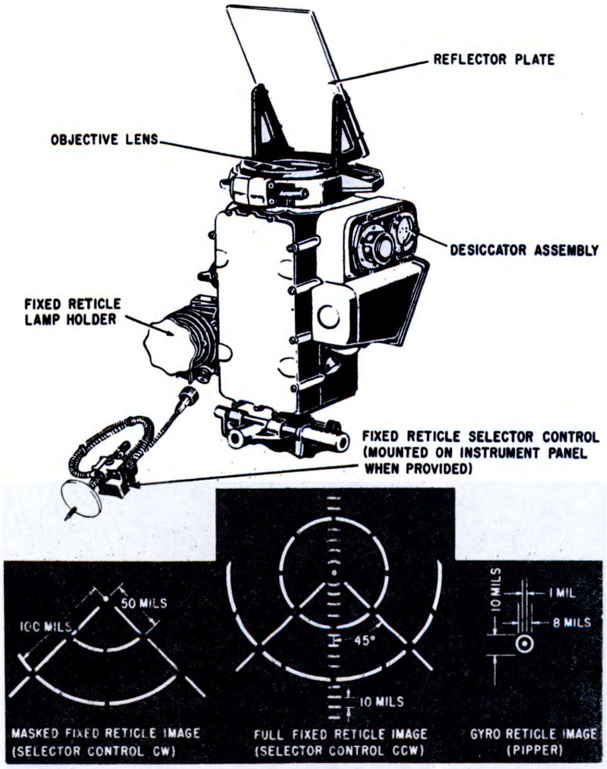
COMPUTING SIGHT SYSTEM

The purpose of a computing sight system in a fighter type aircraft is to present to the pilot a correct sight line for aiming the fixed armament aboard the aircraft. In the system to be described (AN/AWG-4), there are provisions for firing guns, rockets, and missiles (Sidewinder). Radar provides capabilities for attacking a target either day or night. However, the pilot must have visual contact with the target to make use of the computing sight unit function. In this chapter only the visual mode of attack is discussed.

SYSTEM OPERATION

The system is an electronic computing system operated by the pilot. Many variables such as range, range rate, air resistance, angle of skid and attack, etc., are fed into a computer unit. The computer accepts the information, solves the problem, and supplies controlled currents to the gyro-operated sight unit. In the day fighter, radar is used to supply range and range rate information to the computer. The pilot acquires the target visually and the firing run is completed with the optical sight unit.

A typical sight unit is the Mk 11 (fig. 15-1) whose function is to present the total lead angle. This is done by presenting two images on a reflector plate—a fixed reticle image and a gyro reticle image (pipper). The fixed image is stationary and boresighted to the armament datum line of the aircraft. The position of the gyro reticle image is used to track the target and is controlled by the gyroscope inside the sight unit. As the aircraft is maneuvered to keep the pipper on the target, the gyro is continuously supplied with currents from the computer. These currents precess the gyro so that it presents the correct lead angle. Figure 15-2 shows the relationship of the fixed image and the gyro image (pipper) in a pursuit course.


REFLECTOR PLATE
OBJECTIVE LENS
DESICCATOR ASSEMBLY
FIXED RETICLE LAMP HOLDER
FIXED RETICLE SELECTOR CONTROL (MOUNTED ON INSTRUMENT PANEL WHEN PROVIDED)
100 MILS
50 MILS
45°
10 MILS
10 MILS
1 MIL
8 MILS
MASKED FIXED RETICLE IMAGE (SELECTOR CONTROL CW)
FULL FIXED RETICLE IMAGE (SELECTOR CONTROL CCW)
GYRO RETICLE IMAGE (PIPPER)

AQ.557

Figure 15-1.—Sight Unit Mk 11.

Before takeoff the pilot selects a firing range at which he desires to commence firing and cages the gyro in the sight unit to prevent it from tumbling. After the radar is locked on the target and the target is visually located by the pilot, he maneuvers the aircraft into a pursuit course. With the gyro caged, the pipper remains near the center of the fixed image due to the large restraining currents. This requires the pilot to estimate the correct lead angle. When he decides that the lead angle is correct, the gyro is uncaged. If the lead angle was properly estimated, the pipper will move from center, drift onto the target, and remain there. As the attacking aircraft closes on the target, the pilot must continue to make the necessary flight corrections to keep the pipper on the target during the entire tracking run.

Up to this point the range used for computation is that which was manually set in by the

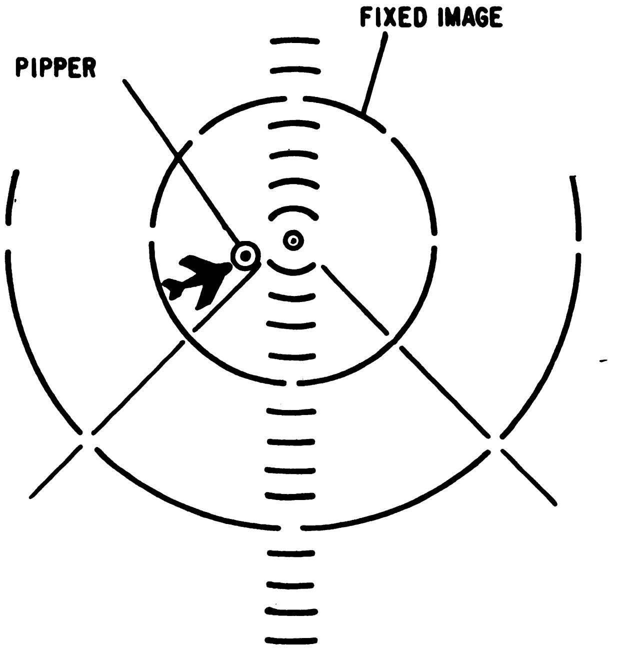


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Figure 15-2.—Leading a target with a gyro pipper.

pilot. Just before the actual range to the target becomes equal to the preselected firing range, radar ranging is automatically switched into operation and a transfer tone is heard in the pilot's headphones to inform him that radar ranging is being used. At the time when the range being presented by the radar is equal to the range preselected for firing, an alert tone is heard. If at this time the pilot has been tracking smoothly for from 1 to 4 seconds, depending on the type of armament to be fired, firing may commence and continue as long as the alert tone is heard. At a predetermined minimum range the alert tone changes to a pulsating tone, warning the pilot to break away from the target, and the attack is terminated.

MAJOR COMPONENTS

The major components (including the radar set) and their location in the aircraft are shown in figure 15-3. These components are discussed briefly in the following paragraphs.

Radar Set

The radar set (items 1 through 8 in figure 15-3) tracks the target and supplies range and range rate to the computer. Radar ranging is used for air-to-air operation only. In any air-to-ground operation, the pilot uses the control box to disconnect the radar from the computer and manually selects a fixed firing range. When the fixed firing range is used, no alert tone is applied to the pilot's headphones. Therefore, the pilot must estimate when the target is within the selected firing range. The solution provided by the computer is accurate for the range selected, but some error is introduced for longer or shorter ranges. For this reason, fixed ranging should never be used in air-to-air operations unless the radar is inoperative.

Sight Unit

As previously mentioned, the purpose of the sight unit (fig. 15-3) is to generate the lead angle. The pilot observes the two images which are projected onto a reflector plate. The images are focused at infinity by the optics of the lens arrangement in the sight unit. As the aircraft is carefully maneuvered to keep the gyro reticle on the target, the gyroscope is automatically and continuously supplied with computed currents to assure that the correct lead angle is presented to the pilot.

Control Box

The control box (fig. 15-4) contains all the necessary controls for energizing the computer group, selecting the mode of operation, and choosing a firing (fixed) range.

Range Unit

The range unit (fig. 15-5) is the tone generator. It supplies three tones to the pilot's headphones. These tones are a 400-hertz transfer tone, to inform the pilot that the system has switched from fixed ranging to radar ranging, a 1,200-hertz alert tone, and a 400/1,200-hertz breakaway tone. A switch on the front panel of the range unit is used to select a bias range that determines when the transfer tone will be heard. The bias ranges that may be selected are 0, 600, 900, 1,200, 1,500, and 1,800 feet. Breakaway range is selected by making the proper wiring connection on a terminal board inside

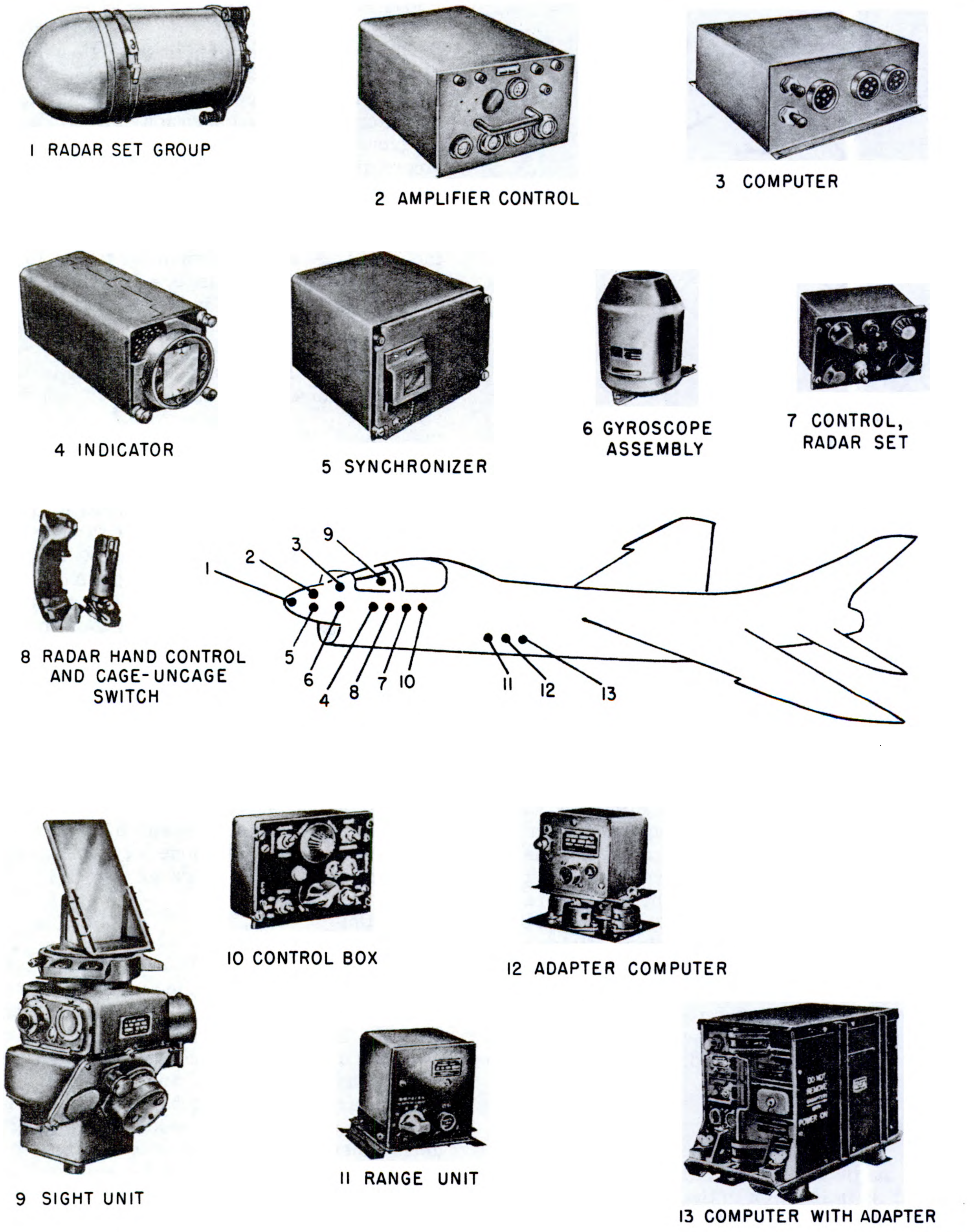

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Figure 15-3.—Armament control system AN/AWG-4.

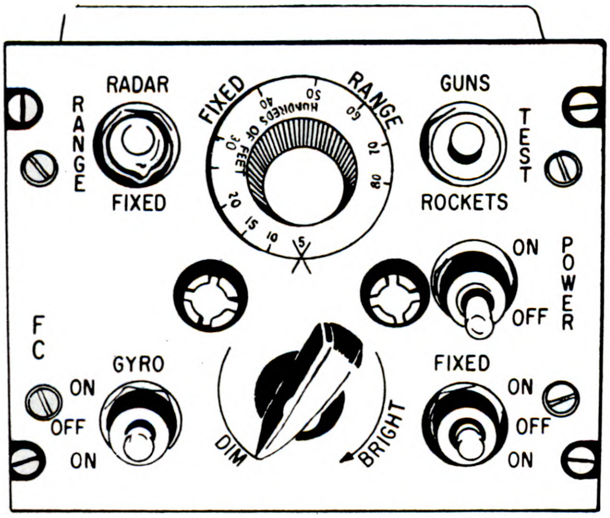

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Figure 15-4.—Control Box Mk 44 Mod 0.

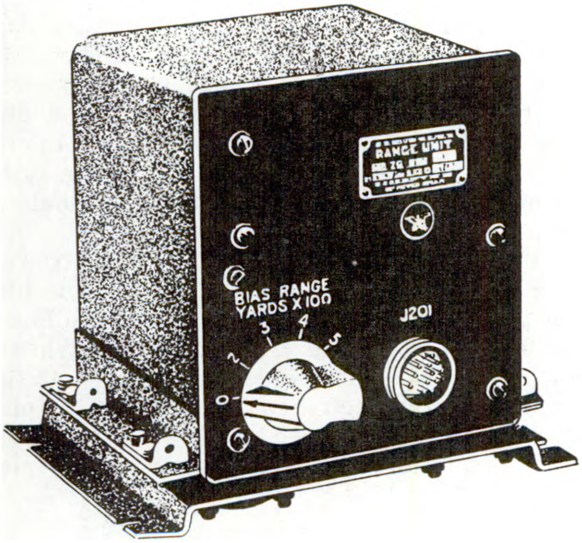

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Figure 15-5.—Range Unit Mk 26 Mod 1.

the range unit. The breakaway ranges that may be selected are 1,500, 1,200, 900, and 600 feet. Both bias range and breakaway range must be selected before takeoff. When tracking a target, the 400-hertz tone informs the pilot that the system has transferred from fixed ranging to radar ranging. One-half second before the firing range is reached, the 1,200-hertz alert tone is applied to the headphones. The pilot may fire as long as the alert tone is heard. The one-half second anticipation time is controlled by a range rate input to the range unit. One-half second before the breakaway range is reached, the alternating 400/1,200-hertz breakaway tone is applied to the headphones, warning the pilot to pull away from the target.

Computers and Adapters

The computer (fig. 15-6) is the brain of the system and computes the ballistic lead. It accepts data on the attack conditions, makes computations for firing, and causes the sight unit to generate the lead angle for obtaining hits on the target. The computer supplies three currents to the sight unit which control the sensitivity (elevation and azimuth offset) of the gyro. These are the sensitivity currents, elevation currents, and azimuth currents. These are used by the sight unit in computing the kinematic lead.

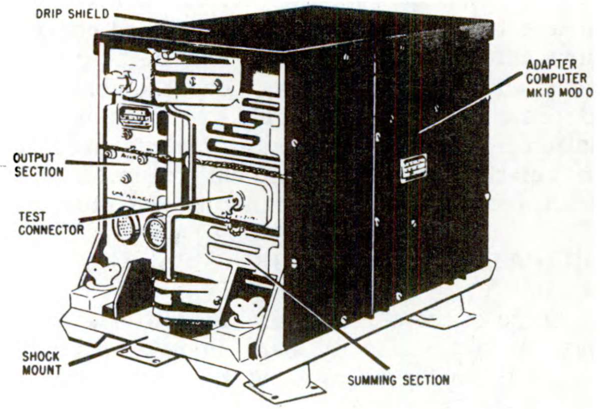

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Figure 15-6.—Computer Mk 101.

The adapter computers (fig. 15-7) are aircraft characteristic plug-in units. They plug into the computer making it possible to adapt to a wide range of weapons and aircraft installations.

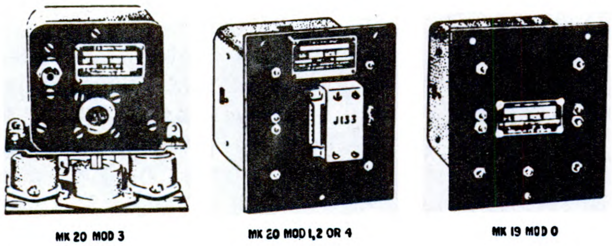

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Figure 15-7.—Adapter computers.

Additional Components

CAGE-UNCAGE SWITCH.—The cage-uncage switch (fig. 15-3) is installed by the aircraft manufacturer. It is located on the radar hand control. When the switch is placed in the caged position, a large amount of current is supplied to the sight unit range coils, and the gyro is restrained. When the switch is in the uncaged position, the gyro is free to establish firing leads.

SKID AND ATTACK ANGLE DETECTORS.—Skid angles and changes in angle of attack must be compensated for when firing rockets. This is due to the tendency of a launched rocket to turn into the airstream. The detectors are mounted in the airstream near the nose of the aircraft and are boresighted to the armament datum line. They sense any change in airflow in relation to the armament datum line and send a corresponding signal to the computer.

OPERATING CONTROLS

Some of the controls required to operate the system have already been mentioned briefly. In the following paragraphs the system operating controls are described in greater detail.

Sight Unit Controls

CAGE-UNCAGE SWITCH.—This switch is placed in the CAGE position at the time the system is energized so that the gyro pipper will remain near the center of the fixed image during flight to the target area and while the aircraft is being maneuvered into a tracking position.

The sight unit is equipped with an antitumble circuit which prevents the gyro from tumbling during violent maneuvers or erratic flight patterns. If the gyro is uncaged under such flight conditions, the gyro will attempt to tumble, but the antitumble circuit will momentarily cage the gyro, tending to return the gyro image to the center of the optical field. This process is repeated as long as the flight pattern is such as to cause the gyro to tumble, and therefore, the gyro image will oscillate. Since an oscillating gyro image would be a poor reference point for maneuvering prior to tracking, it is desirable that the gyro be caged until tracking is initiated. If, when tracking is initiated and the gyro is uncaged, the pipper oscillates near the edge of the field of vision, the pilot will know that the angle off is too great. Since the oscillating image is still visible (a tumbling gyro makes the image unobservable), the pilot may reduce the angle off, permitting the gyro image to remain within limits and indicate the correct lead. If the pilot cannot reduce the angle off and bring the image within limits, the gyro should be caged and a new approach made.

After the radar has locked on a target and the aircraft has been maneuvered into a tracking position with the lead angle estimated, the cage-uncage switch is set in the UNCAGE position. The gyro pipper is then alined on the target by further maneuvering of the aircraft. A short period of tracking enables the system to compute the correct point of aim for firing. After completing the attack run, the pilot should return the switch to the CAGE position.

FIXED RETICLE CONTROL.—The fixed reticle selector control enables the pilot to blank out part of the fixed image in case the full image is distracting during tracking runs. When the knob is fully counterclockwise, the full fixed image may be seen through the reflector plate. When the knob is turned clockwise, the masked fixed image is seen through the reflector plate. (See fig. 15-1.)

Control Box Mk 44 Mod 0

The Control Box Mk 44 Mod 0 (fig. 15-4) provides a central control panel for the fire control system. It is mounted in the cockpit within convenient reach of the pilot.

The power switch serves as a master system switch for delivering power to the computer group. When this switch is turned on, voltage is applied to the gyro and fixed lamp switches.

However, no power is fed to the computer until the gyro lamp switch is turned on.

The gyro lamp switch energizes the gyro lamp and also the computer circuits. The gyro lamp produces the gyro image seen in the reflector plate, and a power supply located in the computer supplies power to the gyro motor. The gyro lamp switch has two ON positions. Each of the ON positions energizes a separate filament in the gyro lamp. This arrangement provides a standby filament which can be used in case one burns out.

The fixed lamp switch energizes the fixed lamp in the sight unit. This lamp produces the fixed image on the reflector plate. The fixed lamp switch also has two ON positions. Each of the ON positions energizes a separate filament in the fixed lamp.

The dim-bright control serves to vary the intensity of the light produced by the gyro and fixed lamps. Clockwise rotation of this dial causes the gyro and fixed images to become brighter, permitting the pilot to adjust the image brightness to suit the light conditions.

The range switch is used to select the type of ranging to be used—radar or fixed. The switch is placed in the RADAR position for radar ranging or in the FIXED position when the pilot is required to visually estimate his range, as in air-to-ground combat, or during emergencies when the radar set is inoperative.

The fixed range control is used in conjunction with the range switch. When radar ranging is used, the fixed range control is set at the range desired for firing. When target range equals that on the fixed range control, the system signals the pilot by producing a tone in the pilot's headphones. The tone persists in the headphones as long as the aircraft remains within the range limits for firing. The tone starts pulsating when the minimum firing range is reached and then the pilot must pullout from the attack run. The ranging tone is produced by Range Unit Mk 26 Mod 1. The minimum range setting, at which the ranging tone starts pulsating, is fixed in the construction of the computer and cannot be altered by the pilot.

When the range switch (fig. 15-4) is placed in the FIXED position, the fixed range control is positioned at the range value where firing will take place. During an attack, the pilot determines by visual perception when his aircraft has closed to within hitting limits for the preset firing range. (NOTE: This application of the fixed range control should be used only for air-to-ground operations or when the radar set is inoperative during air-to-air attacks.) The setting of the fixed range dial is determined by squadron doctrine.

The guns-test-rockets switch is to adapt the fire control system for the type of armament to be used, and to provide for in-flight testing the fire control system. When the switch is set in the GUNS position, the system may be used for guns only; when the switch is in the ROCKETS position, the system may be used for rockets only. The switch is placed in the TEST position when alinement between the pipper and the flightpath of the aircraft is to be checked. This cages the gyro and removes the gravity offset; the pipper however still responds to changes in angle of attack.

Radar Controls

The radar controls are merely mentioned in this chapter since the overall system includes the radar. The radar and radar controls are described in detail in chapter 12 of this manual.

The radar set control is usually located near the Control Box Mk 44 Mod 0 to provide ease of operation of the entire system. The radar indicator is in the area of all aircraft instruments, so as to be easily seen by the pilot.

Power System Controls

In addition to the system and radar controls, electrical power supplied to the system may be controlled by other switches in the cockpit, particularly the master armament switch and the power switch. The aircraft inverter is usually energized by the power switch on the control box. The console lighting switch of the aircraft controls the power to the panel lamps for the control box dials along with the other instruments in the cockpit. A visual inspection will determine the location of these controls in the aircraft.

Other Controls

The only other controls concerned with operation of the system are in the Range Unit Mk 26 Mod 1. These controls are not accessible from the cockpit and must be adjusted before flight. When this unit is used, the bias range must be set by positioning a switch on the front of the unit. Breakaway range must be set by making the proper wiring connections inside the unit. These adjustments will be made according to squadron policy.

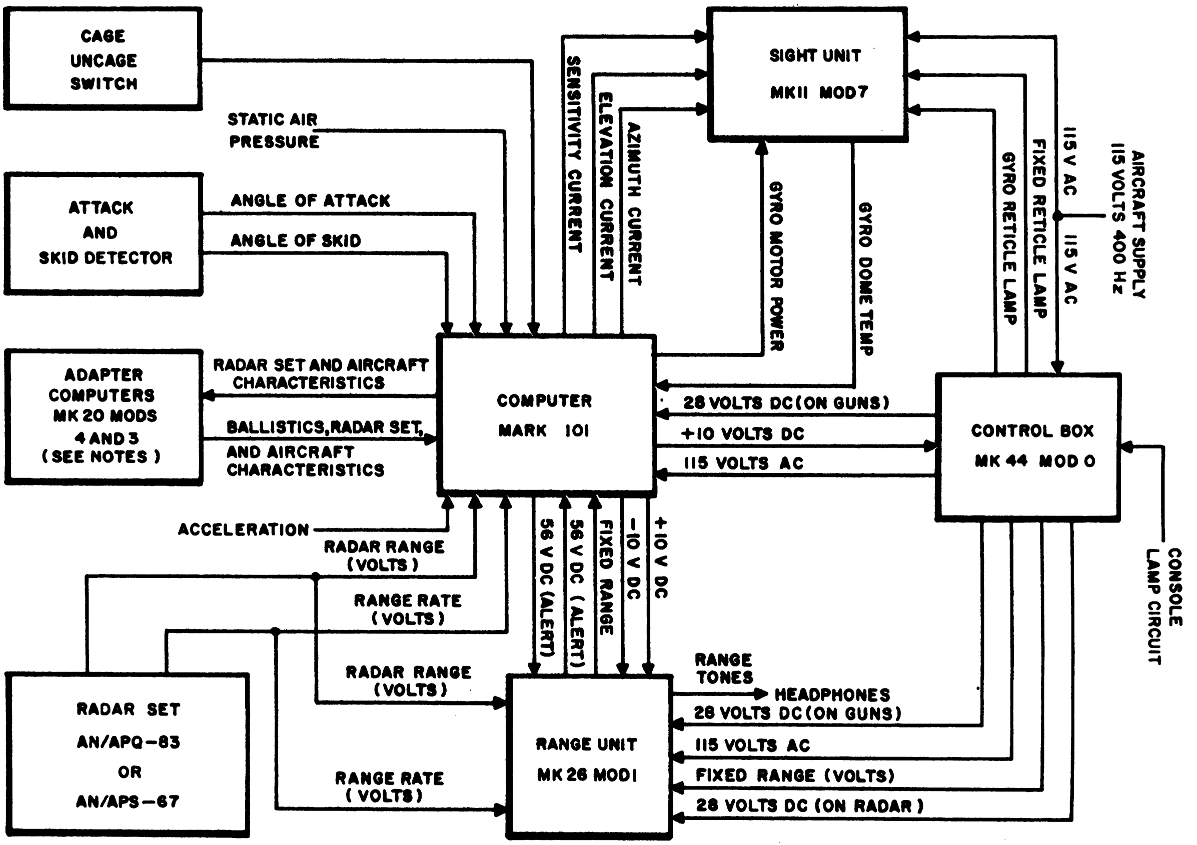
PRINCIPLES OF OPERATION

The problem, as it concerns the fixed armament of fighter aircraft, is to determine a lead pursuit course. It should be recalled from chapter 8, that a lead pursuit course is one in which the armament is aimed, not directly at the target, but at a point in front of the target toward which both the projectile and target travel. Factors affecting a lead pursuit course are: angle of attack, rate of turn, range, range rate, gravity drop, and ballistic constants. The fire control system, using values for these various factors, solves the fire control equations, and by means of an optical sight presents the correct point of aim to the pilot.

The relationship between the various components is shown in the block diagram (fig. 15-8). Notice that most of the components provide input data to the computer and that the outputs of the computer are fed into the sight unit.

OVERALL COMPUTATION

The purpose of the entire system is to position the pipper in the sight unit. This is accomplished by controlling the gyro with electrical currents supplied by the computer. The correct amplitude of these currents is determined within the computer by solution of the problem equations. All calculations are performed



NOTES:
1. MODS 2 AND 3 ARE USED WITH FCS AN/AWG-3
2. MOD 2 OR 4 PLUGS INTO COMPUTER MK 101; MOD 3 IS MOUNTED SEPARATELY

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Figure 15-8.—System block diagram.

automatically; the pilot needs only to turn the power on, acquire the target by radar, operate the cage-uncage switch, and visually track the target.

Sight Unit

The major component of the sight unit is the gyroscope. The gyro operates on the eddy current principles as described in chapter 7 of this manual.

The fixed and gyro images, as seen through the reflector of the sight unit, are shown in figure 15-9. The fixed image always indicates the gun line because it is boresighted to the aircraft datum line. The gyro image is the doughnut-shaped image used in sighting the target. The position of the pipper depends upon four things:

1. The rate of turn of the aircraft.
2. An electrical current to the sight unit called "sensitivity current."
3. An electrical current to the sight unit called "elevation current."
4. An electrical current to the sight unit called "azimuth current."

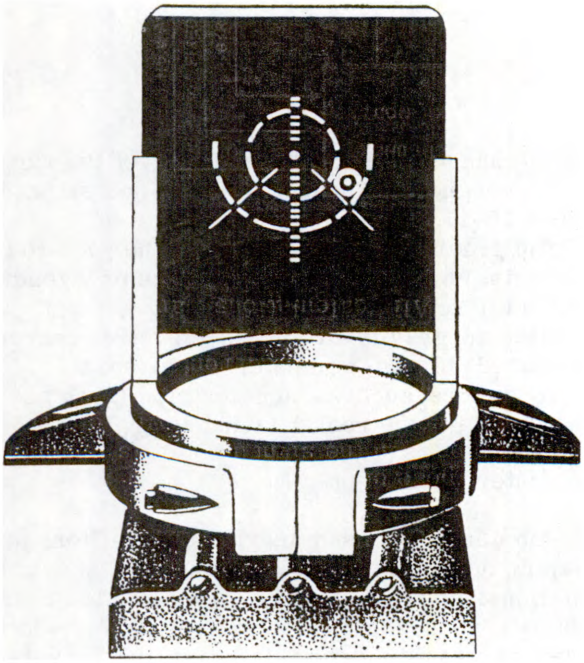

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Figure 15-9.—Reticle images.

The gyro is motor-driven and resists any torque which tends to change the direction of its spin axis. This action is the same as for any gyro, and was described in chapter 7.

A cutaway view of the gyro unit is shown in figure 15-10. The gyroscopic action is produced by the high-speed rotation of the gyro mirror and dome assembly, which is mounted by a universal joint arrangement so that its axis is free to tilt in any direction. Thus when the aircraft turns, the sight unit which is rigidly attached to the airframe, turns around the gyro. The gyro tends to remain fixed in its original position.

The gyro mirror reflects the pipper image on its optical path. Thus, rotation of the gyro with respect to the sight unit housing displaces the pipper image on the reflector plate which indicates the direction the gyro is pointing. Figure 15-11 illustrates the basic principle of the optical system and the action of the gyro used in this sight unit.

While the sight unit turns with the aircraft, the gyro tends to remain pointing in the original direction—the sight unit simply rotates around the gyro. As the axis of the sight unit becomes displaced from the gyro axis, a torque is imposed through the effect of the range current on the gyro attempting to line its axis with the axis of the sight unit. The range current flows through the coils of wire around the gyro to produce a magnetic field.

For an elementary understanding of the sight unit, the range current and coils of wire may be thought of as an electromagnet attached to the sight housing which tends to aline the gyro axis with the aircraft. When the aircraft turns (and hence the sight unit housing) the magnetic force tends to keep the gyro alined with the turning aircraft and the gyroscopic effect tends to keep the gyro pointing in the original direction. The result of the gyro's natural resistance to the magnetic force is that the gyro axis follows the movement of the aircraft but lags behind it. The angular displacement of the pipper equals the lead angle required for that particular attack run. If the turning rate is constant, the pipper lags the fixed image by a constant amount and the indicated lead angle remains constant. A smaller turning rate would generate a correspondingly smaller lead angle, all other factors remaining constant.

If the range to the target is long, the range current is small, the magnetic force is small, the gyro lag is large, and the indicated lead

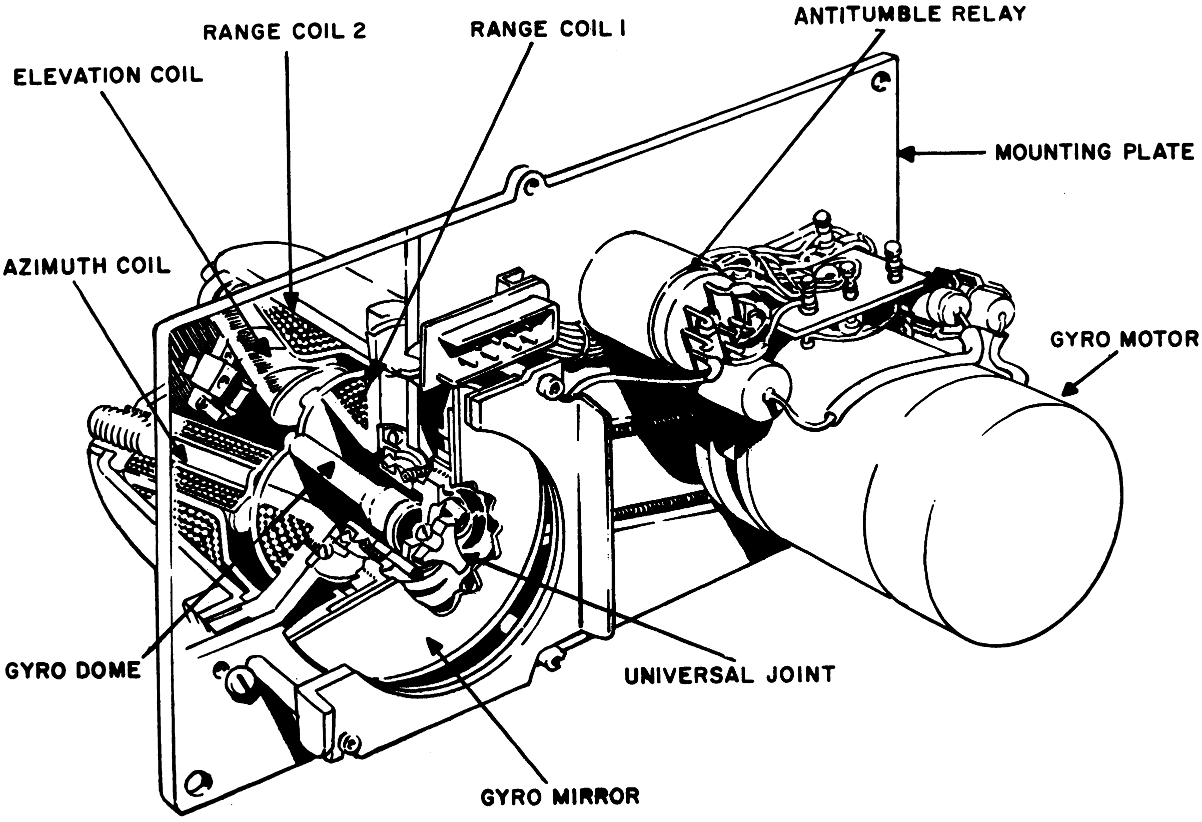

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Figure 15-10.—Gyro Mk 35 Mod 3, cutaway view.

angle is large. This is logical since the farther the projectile must travel, the greater the lead angle must be in order to score a hit. On the other hand, if the range is short (the turning rate of the aircraft is the same as before), the range current is large and the lead angle is small. The magnitude of the range current is determined by information supplied to the Computer Mk 101.

In the preceding discussion the lead angle discussed was that due to the relative motion between the two aircraft, or kinematic lead. The amount of kinematic lead developed depends upon the rate of turn of the aircraft and the amount of range current in the range coils. However, there are additional factors for which compensation must be made. For instance, the gun line must be elevated to compensate for the drop of the projectile due to gravity. Gravity lead is generated in the sight unit by means of a current, supplied to a set of elevation coils, which changes the effective center of the range electromagnet. (These coils are not shown in figure 15-11.)

The gravity correction causes the gyro to be offset downward. Kinematic lead is now generated with respect to this new "zero" point. In addition to gravity drop, the elevation current (produced in the computer) compensates for other factors such as acceleration (g's), angle of attack, and the rocket launcher angle.

Computer Mk 101

The computer uses magnetic amplifiers and shaping networks to perform the necessary calculations. (See fig. 15-12.) A discussion of the methods used and the operations performed is given in greater detail later in this chapter. The magnetic amplifier has been adapted to perform many of the functions previously performed by vacuum tube amplifiers with a great

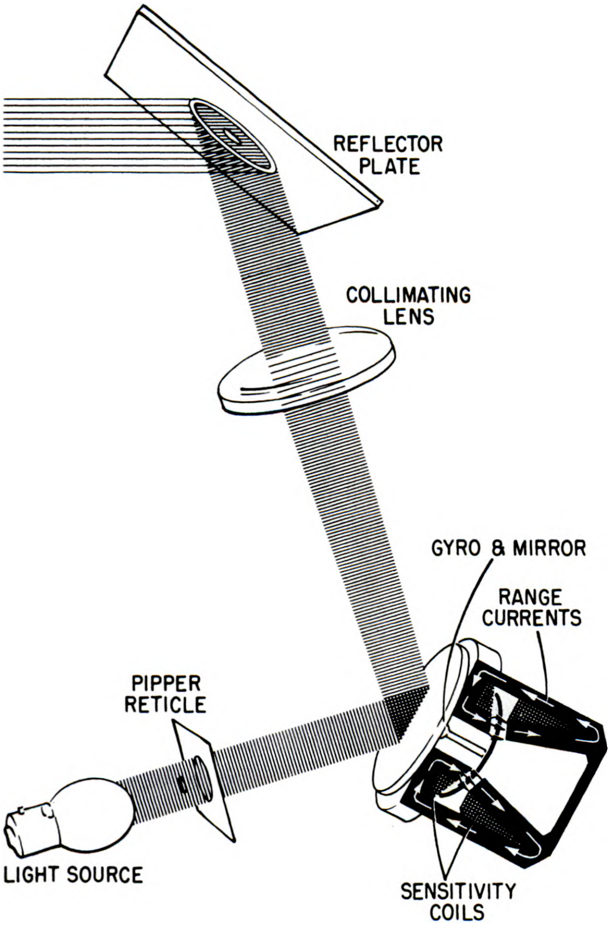

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Figure 15-11.—Basic principle of sight unit.

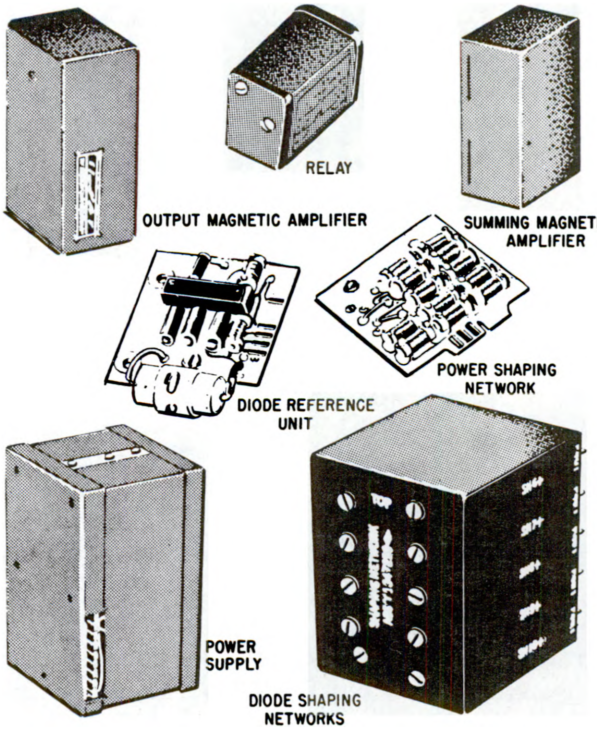

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Figure 15-12.—Computer Mk 101, plug-in units.

reduction in the amount of maintenance needed. The magnetic amplifier is rugged, relatively immune to the effects of vibration, and has a long life. Printed circuits have been used extensively as illustrated in figure 15-13. The computations which the magnetic amplifier and associated shaping networks can perform include addition, subtraction, multiplication, division, raising to a power, and extracting square roots.

One of the currents for which the computer must solve is sensitivity current—the current to the sight unit which controls the generation of kinematic lead. This current depends upon the time required for the projectile to reach the target (time of flight), a small correction due to variations in sight dome temperature, and a correction due to variations in elevation current.

The fundamental factors necessary to determine the time of flight are present range, range rate, and average velocity of the projectile. The radar system determines range; and by a process of differentiation, calculates the rate at which the range is changing (range rate). The average velocity of the projectile is calculated in the computer from the following information:

1. Air density. This must be known in order to compute the amount the projectile is slowed by air resistance. Air density information is supplied by a pressure transmitter, which is an altimeter type device located inside the computer.

2. Aircraft velocity. This will affect the speed of the projectile relative to the airstream and, hence, will have a small effect upon air resistance. Aircraft velocity information is supplied by the adapter computer and is fixed

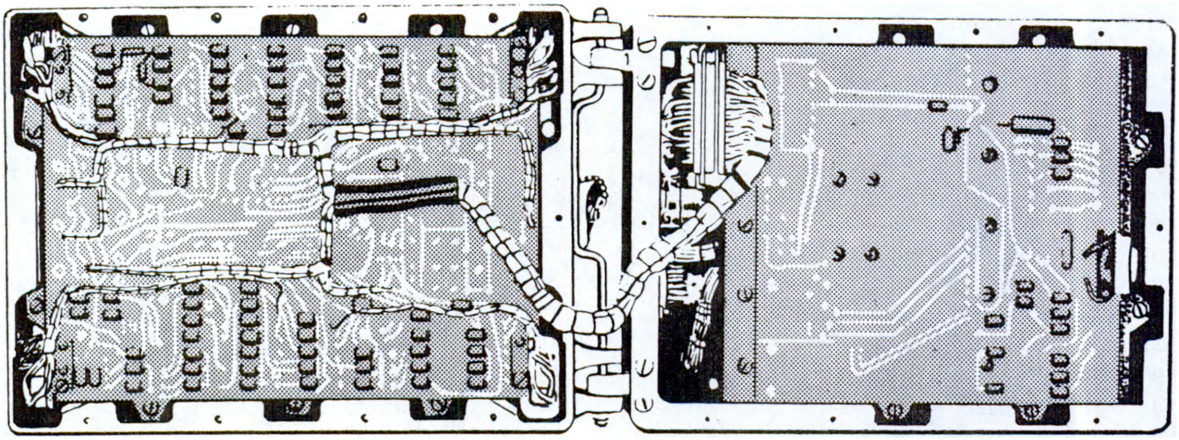

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Figure 15-13.—Computer Mk 101, internal view.

for the type of aircraft and at the most probable combat velocity.

3. Gun and rocket ballistic constants. These are supplied by the adapter computer. (See fig. 15-7.)

The above factors are supplied to the computer and are used to calculate the time of flight of the projectile.

The elevation current is computed by calculating gravity drop and then modifying it according to several variables. Information derived in the range circuits is used to compute the projectile drop due to gravity. This quantity is altered as follows:

1. When the aircraft is in a coordinated bank or pull up, the accelerometer in the computer, together with a factor in the range current computation, determines the correct relationship between the gravity and kinematic offsets even though the elevation coils, in which the gravity correction flows, are not vertical. The accelerometer consists of a weight mechanically linked to the slider of a variable resistance, and mounted so that it measures the normal wing force. Since in all coordinated maneuvers the resultant force on the aircraft is normal to the wings, the distance of travel of the weight is proportional to the force.

2. The true angle of attack is supplied to the computer by the attack angle detector on the aircraft. This corrects the elevation offset necessitated by the weathercocking of the rocket into the airstream as it leaves the launcher. The angle at which the launcher is mounted with relation to the aircraft is supplied by the adapter computer.

3. Utilizing the above information, the computer develops the elevation current necessary to correct for the vertical drop of the projectile.

There are certain restrictions which limit the effectiveness of the system. These limitations are as follows:

1. The system must be receiving a negative range rate while tracking; that is, the attacking aircraft must be closing in on the target. The system will not function correctly if the rate is positive, although the error caused by a small positive range rate is not serious when using guns.

2. The system will compute lead correctly only when the pilot is flying a lead pursuit course; that is, when he continuously tracks the target for a few seconds before and during firing so that his guns are always pointing ahead of the target the required amount to obtain a hit.

COMPUTING TECHNIQUE

Perhaps the most significant difference in the computing methods of the computer used in this system is the fact that d-c voltages are used for all computations. The use of a-c voltages, as was employed previously in some computers, required voltages at various phase angles which complicated the theory of operation. This computer is considerably easier to understand. The computer makes extensive use of common logarithms.

Use of Logarithms

Although the use of logarithms in computer operation was discussed in chapter 13 of this manual, a brief review of the basic properties of logarithms used in the computer is given in the following paragraphs.

An easy way to multiply is by the addition of logarithms; that is, the product of two numbers may be obtained by adding the logarithms of the numbers and taking the antilog of the result.

Similarly, division is accomplished by the subtraction of logs. Raising to a constant power is accomplished by simply multiplying the log by that constant. Since extracting a square root of a quantity is the same as raising it to the 1/2 power, multiplication of the log by the constant 1/2 also extracts the square root—the easy way.

The previous statements may be summarized by the following mathematical symbols:

1. Multiplication by addition—$\log AB = \log A + \log B$.
2. Division by subtraction—$\log \frac{A}{B} = \log A - \log B$.
3. Raising to a constant power—$\log A^2 = 2 \log A$.
4. Extracting the square root—$\log \sqrt{A} = \log A^{1/2} = 1/2 \log A$.

Summing Magnetic Amplifiers

The summing magnetic amplifier is the basic computing element of the computer. This amplifier can add and subtract currents with no interaction between the source currents. When used in conjunction with logarithmic shaping networks, it can multiply, divide, compute powers, and extract square roots. The summing magnetic amplifier is shown schematically in figure 15-14. Note that the schematic is drawn in the form of a triangle. This is a common functional symbol for an amplifier used in a block diagram. The symbol may be compared to an arrow pointed in the direction of signal flow. Normally the external signal connections, represented by heavy circles, are the only ones shown.

In order to measure the algebraic sum of two or more currents, it is necessary to arrange the circuit in such a way that the individual currents will have the same values they would have if the other currents were not in the circuit. Figure 15-15 illustrates the problem. In part (A) of the illustration the application of Ohms Law shows that the current in the top branch is 1 ampere, in the middle branch 2 amperes, and in the lower branch 4 amperes. It would seem logical that the current in the circuit could be measured simply by inserting an ammeter in the circuit as shown in part (B) of the illustration. If the resistance of the meter is assumed to be 1 ohm, then at first glance it might be expected that the meter would read 1 ampere. However, after taking a closer look it should be obvious that the voltage across the original resistors is no longer 12 volts. So the current distribution is no longer as it was originally. In order to maintain the original current distribution the voltage at the junction point must remain zero. This can be done as shown in part (C) of the illustration. Adjustment of the variable resistor to the proper value causes the galvanometer to indicate zero. The ammeter will now indicate the algebraic sum of the currents in the original three branches and there will be no interaction between the branches.

The summing magnetic amplifier is used in a manner similar to the circuit arrangement in part (C) of figure 15-15 to provide the algebraic sum of two or more input currents. The control winding of the magnetic amplifier is connected to the common junction of the input currents in the position occupied by the galvanometer. The output of the magnetic amplifier is fed back to the input so as to oppose the input (degenerative feedback). The result of such an arrangement is that the current through the control winding, and therefore the voltage at the input, is held at or very near zero.

The battery and resistor shown in the dotted box of figure 15-14 represent the equivalent circuit of the signal input to the amplifier. Current flow due to this circuit is in the proper direction to cause an increase in the magnetic amplifier output.

To trace the current flow through the magnetic amplifier, assume that the instantaneous polarity at the top of the transformer is positive. Tracing backward from this point, current flow passes through the upper load winding, through the rectifier CR1, the feedback winding, and the load resistor R_L. To complete the circuit to the center tap of the transformer, the current must flow through the combination of the control winding and the signal input circuit, which are in parallel. If the current in the load is exactly equal to the input current, the potential at the input terminal will be zero; and no current will flow in the control winding.

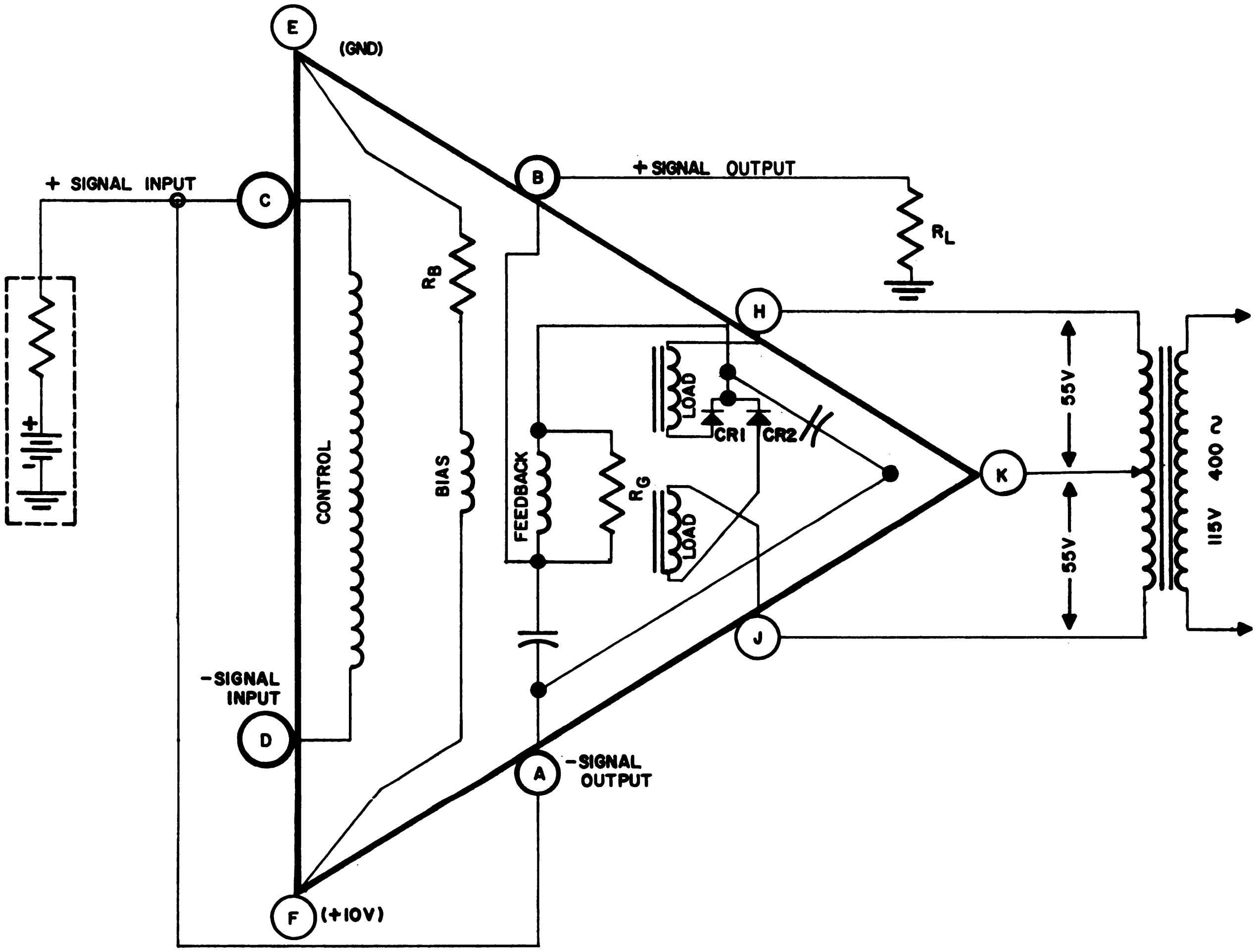

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Figure 15-14.—Summing magnetic amplifier, schematic diagram.

Now assume that the load current is slightly less than the input current. The result will be a slight positive potential at the input terminal. Therefore, a slight current, in the proper direction, will flow in the control winding and cause an increase in the output. The output current, therefore, is always equal to the input current. The range of output currents is controlled by adjustment of the current through the bias winding.

Logarithmic Shaping Networks

In order for the magnetic amplifier to be used to multiply, divide, square, and extract square roots the input quantities are made proportional to the logarithms of the numbers to be used in the computation. The feedback is made proportional to the logarithm of the output current. This is accomplished by the use of shaping networks which are used to approximate the desired logarithmic response curve, as shown in figure 15-16. A curve of this type can be approximated by a resistor network, using diodes to switch in shunt resistors at the proper points on the curve. A network of this type is illustrated in figure 15-17. Although the range of values for the logarithms shown in figure 15-16 is not applicable for use with the summing magnetic amplifiers in the computer, this problem

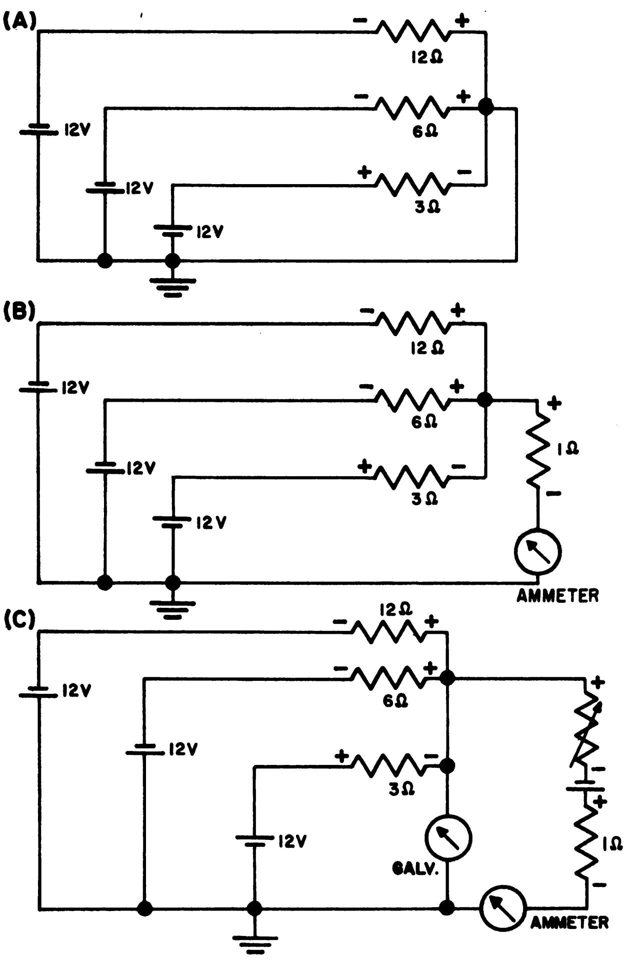

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Figure 15-15.—Addition of currents.

is overcome by multiplying the logarithms by a constant. This will shift the values to a more usable range. The computation is not affected in any way by this multiplication since it appears in all terms of the logarithmic equations; therefore, it cancels out. The scale factor of 2π was found to provide a useful range of values when used as the constant.

It can be seen in figure 15-17 that the cathodes of the diodes are biased positive by the voltage divider consisting of the odd numbered resistors and that each diode is biased to a successively higher voltage. For small input currents the voltage drop across R_L is not sufficient to overcome the bias on any of the diodes, so the output current is equal to the input current. As the input current increases, a point is reached where the voltage drop across R_L is equal to the drop across R1. Above this current value the voltage at the anode of CR1 is greater than the voltage at its cathode and some current is shunted through R2. As the input current continues to rise, a point is reached above which CR2 conducts and shunts current through R4. The resistor values in the network are selected in such a way that the ratio of load current (I_O) through R_L to total input current (I_{in}) is a close approximation to the equation $I_O = 2\pi \log_{10} I_{in}$. The diodes are reversed and biased from a negative supply when the desired input and output currents are negative.

COMPUTING OPERATIONS

Only the basic ideas of the computing operations are presented in this course, since to analyze the mechanization of the equations used in the computer would be too lengthy.

Addition and Subtraction

The method used for simple addition and subtraction is illustrated in figure 15-18. As previously described, the current through the control winding of the magnetic amplifier is held at zero by feedback (I_{FB}), then $I_{FB} = I_A + I_B - I_C$. In this circuit all of the output current (I_O) is fed back to the input, so $I_O = I_{FB} = I_A + I_B - I_C$. In most cases the output of one magnetic amplifier is used as the input to another magnetic amplifier. Remember, the input voltage is held at zero; therefore, this point can be considered as virtual ground. A special symbol shown connected to the load resistor is used to indicate this condition.

Multiplying by a Constant

An illustration of how the output current can be made a fixed multiple of the input current, by multiplying by a constant, is shown in figure 15-19. It can also be seen by using Kirchoff's Law that $I_O = I_{FB} + I_X$. When multiplying by a constant, $\frac{R1 + R2}{R2}$ is used to produce the constant. If I_X is made equal to I_{FB}, as will be the case if R1 is made equal to R2, then $I_O = 2I_{FB} = 2(I_A + I_B - I_C)$. This can be verified as follows because the feedback is the result of the voltage at terminal A divided by R1:

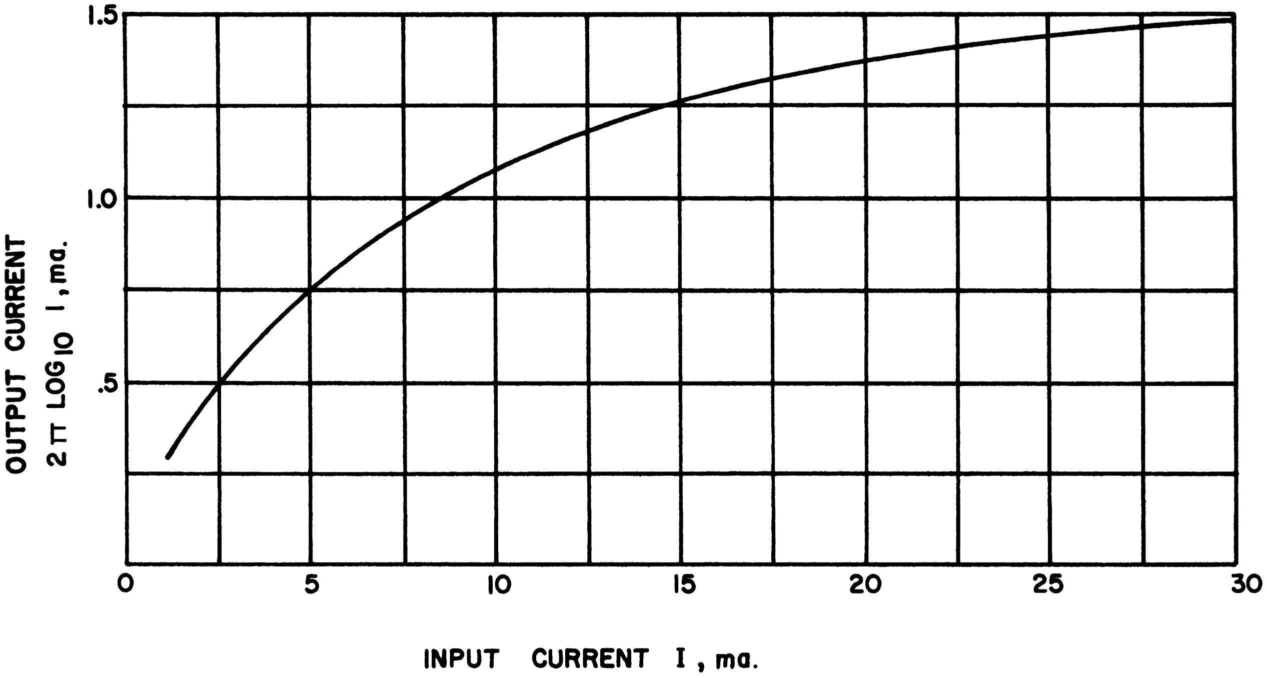

Figure 15-16.—Logarithmic curve.

$$I_{FB} = \frac{E_A}{R1} = I_O \frac{\frac{R1R2}{R1 + R2}}{R1} = I_O \frac{R2}{R1 + R2}$$

Summing the currents at terminal C produces:

$$I_{FB} = I_O \frac{R2}{R1 + R2} = I_A + I_B - I_C$$

or

$$I_O = \frac{R1 + R2}{R2} (I_A + I_B - I_C)$$

Multiplication and
Division by Variables

The method used to multiply and divide by variables is illustrated in figure 15-20. This illustration shows a shaping network in the feedback circuit. It is assumed that the input signals have already been converted to logarithms by a shaping network which, as should be recalled, produces an output current equal to 2π times the log of the input current.

The negative shaping network shown in figure 15-20 produces a feedback current equal to 2π log I_O. When summing the currents at terminal C the result is:

$$2\pi \log I_O = 2\pi \log I_A + 2\pi \log I_B - 2\pi \log I_C$$

Dividing both sides of the equation by 2π gives the following results:

$$\log I_O = \log I_A + \log I_B - \log I_C$$

Recalling the rules of logarithms, as previously discussed, it can be seen that the above equation can be reached as follows:

$$\log I_O = \log \frac{I_A I_B}{I_C}$$

$$I_O = \frac{I_A I_B}{I_C}$$

which is the equation solved by the summing magnetic amplifier.

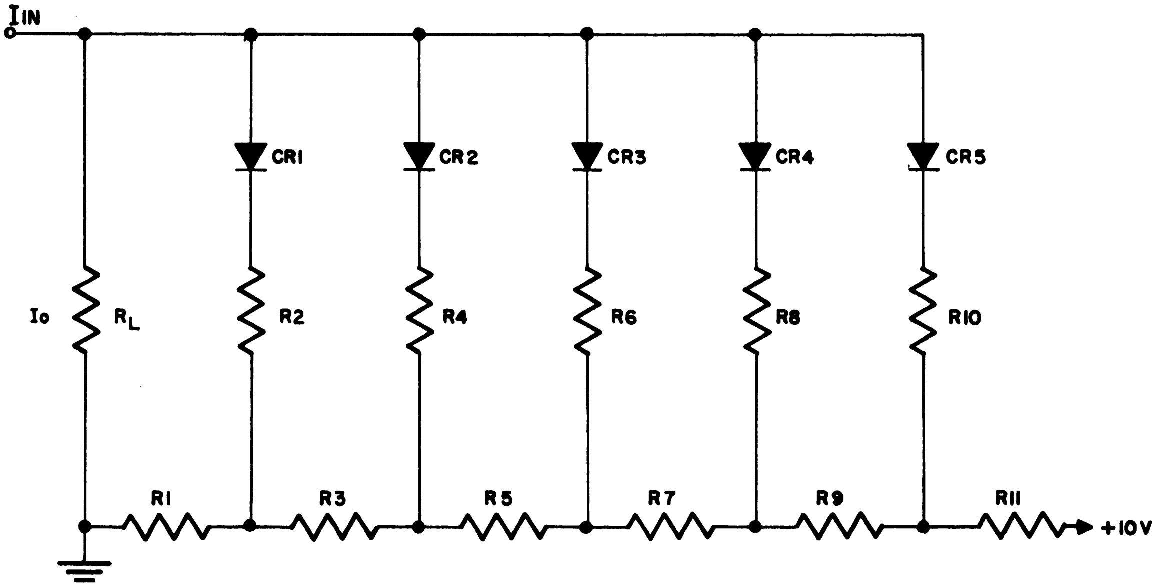

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Figure 15-17.—Logarithmic shaping network.

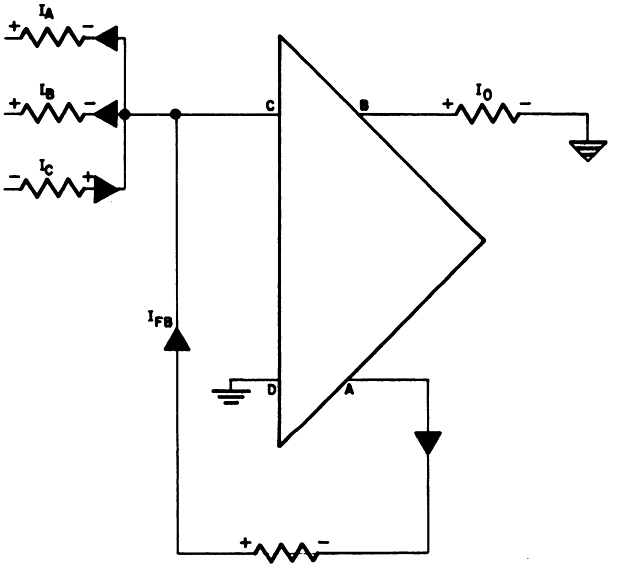

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Figure 15-18.—Addition and subtraction.

Raising to a Constant Power

The circuit arrangement used to raise the output current to a power is shown in figure 15-21. The portion of the output current as shown in the figure is $2\pi \log I_O$. The two resistors R1 and R2 cause this current to divide so that the feedback current equals $\left(\frac{R2}{R1 + R2}\right)$ $2\pi \log I_O$. Summing the currents at the input to the magnetic amplifier produces the following equation:

$$\left(\frac{R2}{R1 + R2}\right) 2\pi \log I_O =$$

$$2\pi \log I_A + 2\pi \log I_B - 2\pi \log I_C$$

Dividing both sides by 2π yields the following:

$$\frac{R2}{R1 + R2} \log I_O =$$

$$\log I_A + \log I_B - \log I_C$$

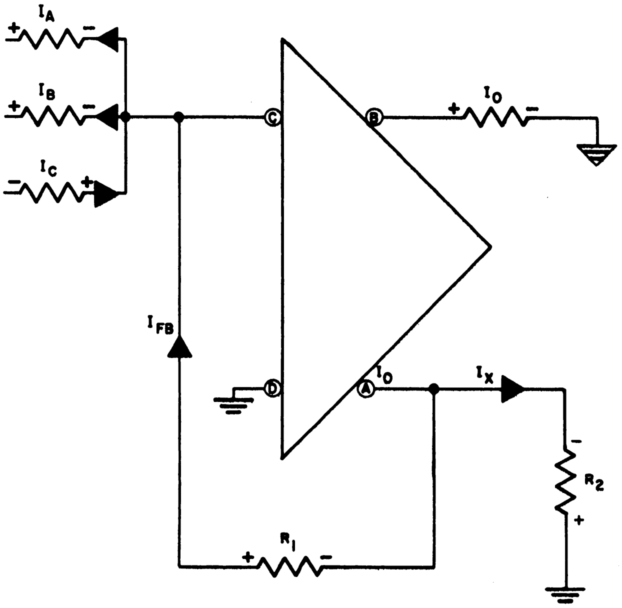

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Figure 15-19.—Multiplying by a constant.

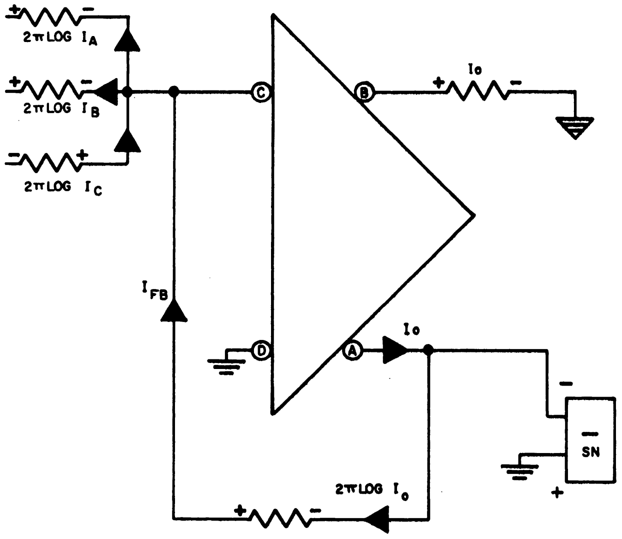

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Figure 15-20.—Multiplication and division.

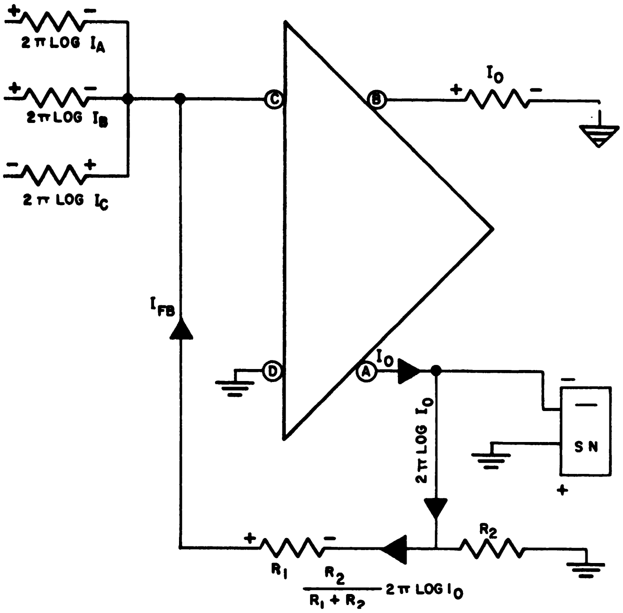

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Figure 15-21.—Raising to a power.

Applying the rules for logarithms, the equation may be simplified as follows:

$$\frac{R2}{R1 + R2} \log I_O = \log \left(\frac{I_A I_B}{I_C}\right)$$

Multiplying each side by the reciprocal of $\frac{R2}{R1 + R2}$ results in the following:

$$\frac{R1 + R2}{R2} \times \frac{R2}{R1 + R2} \log I_O =$$

$$\frac{R1 + R2}{R2} \log \left(\frac{I_A I_B}{I_C}\right)$$

$$\log I_O = \frac{R1 + R2}{R2} \log \left(\frac{I_A I_B}{I_C}\right)$$

Again applying the rules for logarithms the equation may be expressed as follows:

$$\log I_O = \log \left(\frac{I_A I_B}{I_C}\right)^{\frac{R1 + R2}{R2}}$$

$$I_O = \left(\frac{I_A I_B}{I_C}\right)^{\frac{R1 + R2}{R2}}$$

If R1 and R2 are made equal the equation is expressed as follows:

$$I_O = \left(\frac{I_A I_B}{I_C}\right)^2$$

Extracting Roots

The method used to extract a root is illustrated in figure 15-22. In this illustration note that the input currents have been divided by 2 before they are applied to the amplifier input. Also the full logarithm of the output current is fed back. The resulting logarithmic equation is expressed as follows:

$$2\pi \log I_O = \pi \log I_A + \pi \log I_B - \pi \log I_C$$

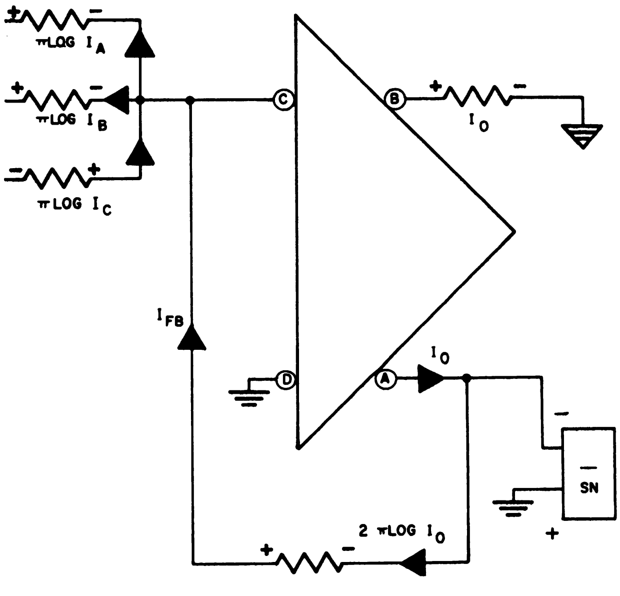

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Figure 15-22.—Extracting roots.

Dividing both sides of the equation by π yields the following:

$$2 \log I_O = \log I_A + \log I_B - \log I_C$$

Using the rules for logarithms this may be expressed as follows:

$$2 \log I_O = \log \left(\frac{I_A I_B}{I_C}\right)$$

$$\log I_O^2 = \log \left(\frac{I_A I_B}{I_C}\right)$$

$$I_O^2 = \left(\frac{I_A I_B}{I_C}\right)$$

Taking the square root of each side of the equation results in the following:

$$I_O = \sqrt{\frac{I_A I_B}{I_C}}$$

Other roots may also be obtained by the same method. For instance, if the inputs were divided by 3, the cube root would be extracted.

Solution of a Typical Problem

The method of connecting several magnetic amplifiers to solve a specific problem is illustrated in figure 15-23. In this circuit, three input currents, a constant, and a shaft rotation are involved.

The output current of summing magnetic amplifier No. 1 is made equal to its current, and this output current is applied to a logarithmic shaping network. The load resistance of the shaping network is composed of two equal resistors effectively in parallel so half of the current flows through each resistor. The output current of summing magnetic amplifier No. 2 is divided between two equal resistances at terminal A, making the feedback current only half the output current. As a result, the output current must be twice as great as the input current. This output is applied to a logarithmic shaping network and the resulting current is divided equally between the two load resistors. The operation of summing magnetic amplifier No. 3 is identical to that of No. 1 except that the input and output currents are negative.

The currents representing half the logarithms are fed to the input of summing magnetic

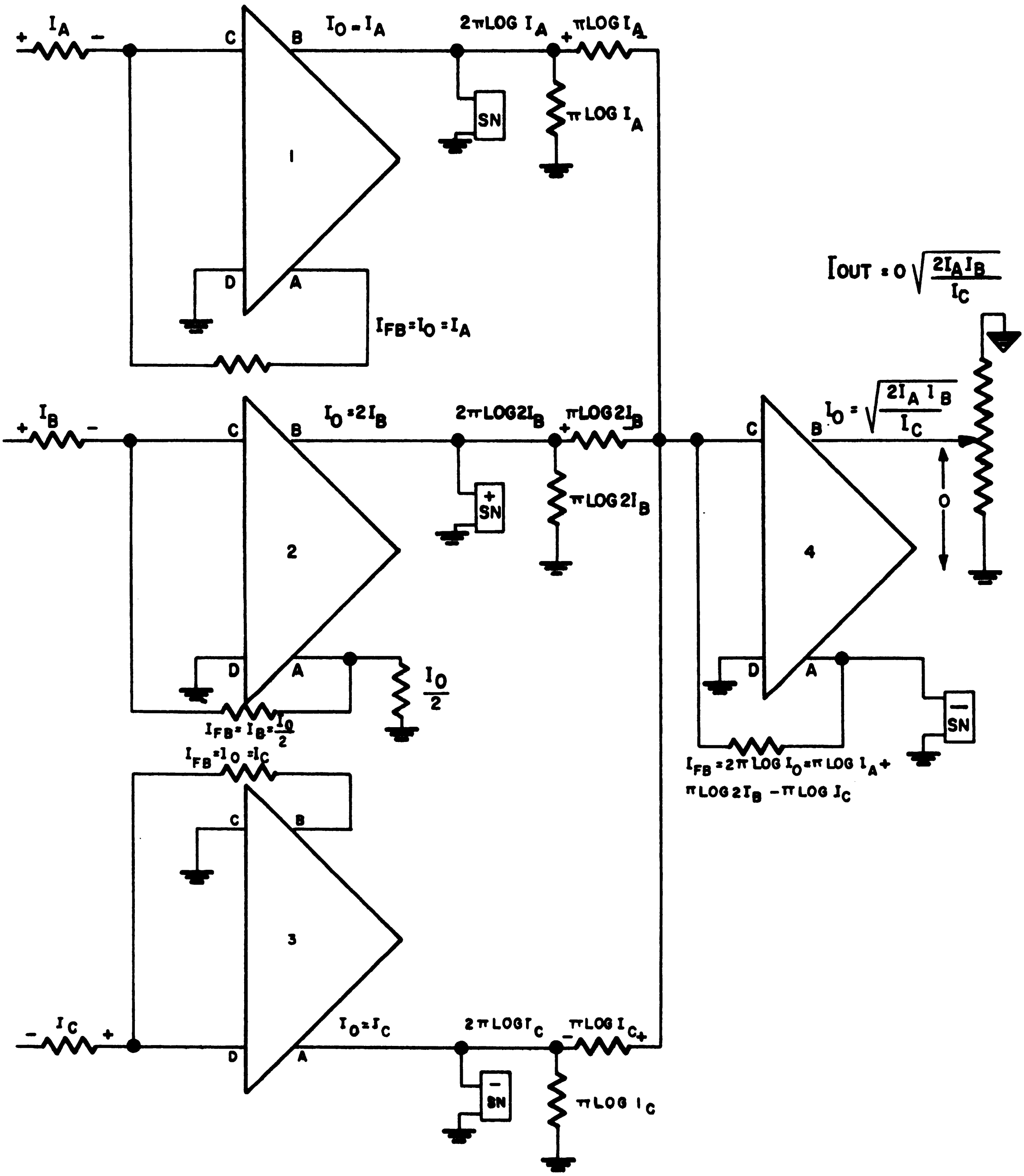

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Figure 15-23.—Solving a typical problem.

amplifier No. 4. The feedback for this magnetic amplifier is modified by a logarithmic shaping network, so the output current of the magnetic amplifier is equal to the antilog of the input current. As a result, the output current must equal

$$\sqrt{\frac{2I_AI_B}{I_C}}$$

This current is applied to the moving arm of a potentiometer which is connected between ground and an output virtual ground. If θ is equal to the resistance from ground to the moving arm divided by the total resistance of the potentiometer, the current in the virtual ground will be

$$\theta\sqrt{\frac{2I_AI_B}{I_C}}$$

MAINTENANCE

Service experience indicates that only a small amount of maintenance is required to keep the system in an operational status. Malfunctions can result in total failures, partial failures, or inaccuracies. Total and partial failures are usually evident at once, but because of the nature of the equipment, some serious malfunctions may not be apparent in system use or during the preflight checks. Inspections and carefully performed tests, done at periodic intervals, will assure peak performance of the system.

In the following paragraphs the major units not specifically mentioned do not require special consideration with respect to maintenance. Maintenance of these units is considered to be general and is discussed later in this manual.

TECHNICIAN'S PREFLIGHT TEST

The preflight check is a routine visual and operational check of the computer group to verify its operational readiness before the aircraft takes off on a firing mission. It is designed to detect the more obvious type of troubles in a minimum amount of time.

Two types of preflight tests are available for squadron-level testing. The particular test to be used will depend upon available time and personnel and operating conditions. When conditions permit, it is recommended that the technicians preflight test be conducted using the test equipment provided especially for this system.

PERIODIC CHECK

The periodic check of the system is performed in a manner similar to that of any other electronic system test, which requires the strict adherence to an outlined step-by-step procedure.

The periodic check is designed to determine if the system meets minimum performance standards as set forth in the outlined procedure. The tests performed during the check establish that the computer and sight unit are functioning properly, or will indicate and localize a malfunction to one of the units mentioned above, or to the control box.

If the radar is operating properly, but there is an absence of the ranging tones, the periodic check will pinpoint the trouble either to the computer alert circuit or to the range unit.

Any defective unit or component indicated by these checks should be removed from the aircraft and subjected to tests as specified in the Maintenance Instructions Manual.

BENCH TESTS AND REPLACEMENT OF PARTS

When the periodic check reveals a malfunction in the system, further testing of the individual unit is usually required to localize the trouble to a specific circuit. There are several pieces of test equipment provided for this purpose. Detailed instructions for the use of this equipment are contained in the manual for the particular test equipment being used.

Sight Unit Maintenance

Because special equipment and personnel with special training are required to repair this unit, maintenance of the sight unit in the field is limited.

The only maintenance performed in the field is cleaning of the reflector plate and objective lens, replacement of the fixed and gyro reticle lamps and the reflector plate, and testing. For other defects, the sight unit should be replaced and sent to an overhaul activity.

The objective lens and reflector plate are surfaced with a special coating. To keep them free of dust use lens tissue or a soft brush such as a camel's-hair brush and wipe very lightly. To remove dirt streaks or smudges, a solution consisting of distilled water—2 ounces;

ammonium-hydroxide—2 to 4 drops; and household detergent—40 granules is permitted. Use a soft lint-free cloth and rub gently. Harsh cleaners and hard rubbing will damage the coated surfaces.

During normal operation air flows into and out of the sight unit as the aircraft changes in altitude. This air must be free from moisture. The sight unit is equipped with a special air drying system for removal of moisture. As the aircraft descends, the air pressure outside of the sight unit increases and air is allowed to pass through a desiccant unit (filled with silica gel crystals) which absorbs the moisture present in the air. On ascent, the air pressure inside the sight unit is greater than the air pressure outside and the air now flows out; at this time an automatic heating unit is energized and the moisture previously absorbed is evaporated and carried out with the outward flow of air. This provides dry crystals for each time air enters the sight and prevents any accumulation of moisture inside the sight unit.

To allow for proper operation of the drying system, the sight unit is sealed when it is assembled. Proper operation of the desiccant unit is indicated by the color of the silica gel crystals. If the crystals are blue, the dryer is operating properly; if they are pink, it indicates the presence of condensed moisture in the sight unit. If the crystals are pink, the sight unit must be removed and returned to an overhaul activity for repair and replacement of the automatic dryer unit.

Computer Maintenance

The maintenance of the computer is accomplished by the isolation of and the replacement of the complete plug-in units and printed circuit boards. Field repair of defective plug-in units and printed circuit boards is not considered practicable; and under normal conditions, no attempt should be made to repair them. Defective items should be returned to overhaul for repair. Plug-in units which are found to be defective are replaced with new units. After replacing the defective unit, the computer should again be subjected to the tests to be sure all trouble has been eliminated.

CHAPTER 16
ELECTRIC POWER AND GROUND COOLING SYSTEMS

In order to operate and maintain the complex electronic installations of modern naval aircraft, the technician must be familiar with the electric power system of the particular aircraft with which he is associated. Since the electronic installations of aircraft vary widely according to the size and configuration of the aircraft, the electric power requirements and the electrical system components of aircraft also vary. Therefore, the technician must also have a basic understanding of the component parts of the electrical system—the power generation equipment, the conversion units, the power control, regulation, and protection devices, and the general power distribution systems—of a typical aircraft.

Today's technician must also have an understanding of the capabilities and limitations of the auxiliary power sources provided for use in ground servicing and maintenance of aircraft. He must be able to operate these units, and must be familiar with the proper procedures for connecting and disconnecting the auxiliary power units to the aircraft. He must know the proper procedures for servicing the auxiliary units, and must observe and enforce all safety precautions and regulations concerning the use of these units.

The technician must also know the requirements for cooling the various electronic equipment while on the ground. He must be familiar with the sources of auxiliary air and cooling. He must know the operating procedures as well as the capabilities and limitations of the various cooling units.

This chapter is devoted to a discussion of these topics. In most sections, the topics are discussed in general; in a few instances, details are presented as they pertain to specific topics or items of equipment. Coverage of equipments is limited to those expected to be in common usage during the life of this course.

AIRCRAFT POWER

The electric power system of an aircraft consists of the power source and its associated controls, the generation system and its associated control and regulation, the conversion units, the feeder and distribution system and its component parts, and the various protective devices used throughout the installation.

Most older types of aircraft used engine-driven generators to produce d-c power at a nominal 27.7 volts. Inverters and dynamotors were used as conversion units to produce the voltages required for operation of the individual equipment. With the comparatively simple installations then in use, this arrangement was satisfactory; however, as the installations became more complex, weight problems arose. The increased weight (which resulted from the addition of more and more inverters and dynamotors) soon became prohibitive. A new approach to the problem was required.

As part of the overall effort to standardize aircraft and electronic installations, the supply and distribution of power offered a logical starting point. The first step was to standardize the supply voltages and power frequencies, and to use generators which would provide the required power. Later in the standardization program, the generation of d-c power was discontinued, and the primary power became exclusively a.c.; the d-c requirement was supplied through transformer-rectifiers. This reduced the number of voltages generated, reduced the number of rotary devices, and allowed the use of smaller conductors in the distribution system. The result was a drastic decrease in the total weight of a given installation, which in turn permitted a more complex installation for a given weight allowance.

Even a partial listing of the considerations involved in any discussion of aircraft electric systems must include the following items in order to be of any real value:

1. A "main generating source" refers to all generator units driven by a specified engine; thus a single-engine aircraft can have only one main source.

2. Multiengine aircraft may have a main generating subsystem for each engine. This is the usual practice, but it is not universally followed.

3. In multigenerator systems, provisions may or may not be made for parallel operation of generators producing similar power. If parallel operation is provided, provisions must also be made for individual operation of the subsystems in the event of a failure within the paralleling system.

4. Adequate frequency regulation and stability in a-c generation systems require some method of speed control of the generator's rotor drive mechanism.

5. Provisions must be made to insure that adequate power is available in each mode of operation. In the event of failure of the aircraft engine or its associated generation system, the maximum amount of power which can be produced is decreased. In the case of single-engine aircraft this automatically constitutes an emergency situation.

6. The failure of a single generator or engine in a multiple installation does not constitute the same degree of emergency as the same failure in a single-engine installation. Although some restrictions are placed on operational capabilities, some degree of safety may usually be maintained with the remaining engines and generators.

7. Provisions should be made to enable use of external power sources for starting the engines while on the ground and for ground operation without using the aircraft engines. The aircraft electric system must include provisions to prevent applying both internally generated power and externally furnished power to the system at the same time.

AIRCRAFT ELECTRIC SYSTEMS

The electric system of each model aircraft has features which are peculiar to it alone, while other features are common to most models. This section is devoted primarily to a general discussion of the electrical system of a typical aircraft.

Source of Power

The basic source of power for the electrical system is the aircraft engine. An a-c generator requires a constant rotational speed in order to produce a constant frequency output. In most modern aircraft, a constant speed drive (CSD) unit is inserted between the aircraft engine and the a-c generator for this purpose.

The constant speed drive unit acts as a variable-ratio differential transmission system which converts the variable speed of the engine to the constant speed required by the generator. The engine is mechanically coupled to the input of the CSD unit; the output of the CSD is mechanically coupled to the rotor of the generator. Internal coupling between the input and output sections of the CSD unit is usually hydraulic, using the engine's oil supply as the transmission coupling medium. Output speed of rotation is controlled by means of mechanical governors and/or electronic speed regulators.

Generation System

The heart of the electric generation system is the constant-speed, wye-connected, a-c generator. This unit normally produces a 3-phase output voltage of about 120-208 volts at 400 Hz which is subsequently regulated to 115/200 volts. The basic theory of a-c generators is discussed in Basic Electricity, NavPers 10086-B.

An underspeed switch is normally connected to the output shaft of the CSD unit. This is a centrifugally operated switch and is normally in the open position; it closes only when the output end of the CSD (which is also the generator shaft) reaches a preset speed of rotation. When the switch is open, the electrical system cannot be energized. An overspeed switch is also sometimes used.

D-C GENERATOR.—In most older aircraft, all electric power was generated as d.c. In most of the newer aircraft, no d.c. is generated; the d-c requirements are met by transforming and rectifying the a.c. In some presently operational aircraft, however, the main power generation system provides both a-c and d-c voltages from a common unit. In other aircraft models, a separate generator is used to provide the d-c power required for operation of the d-c components. This method is not common in airborne applications because of the limited number of prime movers (engines) available.

The basic theory of d-c power generators is presented in Basic Electricity.

EMERGENCY GENERATORS.—In the event of failure or shutdown of the aircraft's engines or main generators, the electric system becomes inoperative. The aircraft, however, must have electrical power in order to maintain adequate flight control. All naval aircraft incorporate an auxiliary or emergency generator which operates independently of the aircraft engine.

The most common type of emergency generator is the ram air turbine (RAT). It is normally enclosed within the fuselage, being projected into the airstream when its operation is necessary. Driving power for the rotor is derived from the movement of a turbine through the air; it can be operated only in flight or with blast air when on the ground.

Due to its relatively small size, the emergency generator cannot supply the electric loads required for normal operation of the aircraft. Therefore, only those systems and equipments considered essential for the maintenance of flight are operable when the aircraft is dependent on the emergency generator.

Because the rotor of the ram air turbine generator turns at a variable speed (dependent on the speed of the aircraft in flight), frequency stability is not so refined as that of the main generators. A governor is usually incorporated to limit rotational speed; the frequency is thus prevented from becoming too high. No solution has yet been found for maintaining operation of the generator when the aircraft speed drops below a certain point. Therefore, in the event of a power-off landing, all electric power and stability control is lost before the aircraft rolls to a full stop.

System Voltage Regulation

Voltage regulators are incorporated in all electric generation systems. Although similar in basic purpose, the configuration and details of operation vary with each type. Basic theory of voltage regulation and regulator devices is presented in chapters 16 (for a.c.) and 18 (for d.c.) of Basic Electricity. A practical 3-phase a-c static voltage regulator, specifically designed for aircraft usage, is shown in simplified form in figure 16-1 and discussed in the following paragraphs.

The voltage sensing circuit of the regulator incorporates a highest phase takeover (HPT)

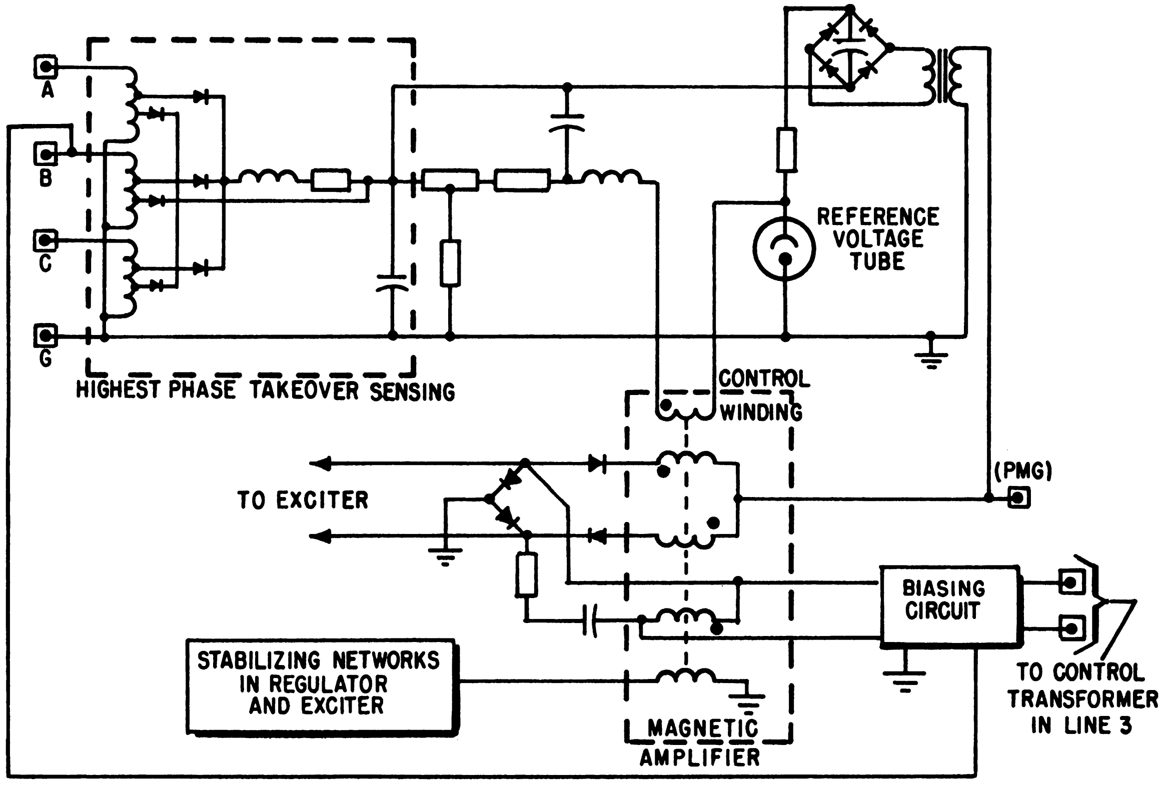
A
B
C
G
HIGHEST PHASE TAKEOVER SENSING
REFERENCE VOLTAGE TUBE
CONTROL WINDING
TO EXCITER
(PMG)
BIASING CIRCUIT
STABILIZING NETWORKS IN REGULATOR AND EXCITER
MAGNETIC AMPLIFIER
TO CONTROL TRANSFORMER IN LINE 3

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Figure 16-1.—Voltage regulator, simplified schematic.

circuit developed specifically for aircraft systems. This circuit permits regulation of the average of the 3-phase voltages during normal system operation and during slightly unbalanced conditions of the system. Large unbalanced load conditions result in large unbalanced voltages. The HPT circuit allows regulation of the highest individual phase-to-neutral voltage. The unit thus incorporates the advantages of both the average voltage sensing circuit and the highest phase voltage sensing circuit.

The output of the HPT circuit is compared with an accurate voltage obtained from a cold cathode voltage reference tube. Any difference between the sensed voltage and the voltage reference causes a current to flow in the control winding of a magnetic amplifier. This amplifier is energized by a single-phase a-c voltage, such as that produced by the permanent magnet generator previously discussed. The current in the control winding determines the current output of the PMG to the magnetic amplifier output circuit. The output of the magnetic amplifier supplies the control winding of the saturable current potential transformer (SCPT).

If the voltage rises at the generator terminals, the output voltage from the sensing circuit increases. This in turn increases the error signal between the sensing circuit and the glow tube reference, and adds to the current in the control winding of the magnetic amplifier. The increased current tends to increase the magnetic amplifier's output current, which then passes through the control winding of the SCPT and makes it behave more like an air core transformer. This reduces the output power. Since the output power of the SCPT is the input power to the generator field, the terminal voltage of the generator is lowered to its required level.

External Power

Essentially all aircraft have provisions for application of electric power from an external source for starting the aircraft engines and/or for ground servicing and maintenance without operating the engines. This power, while not generated within the aircraft, is part of the overall electric system of the aircraft. It must be in all aspects compatible with the power generated within the aircraft. Under no circumstances may the internal and external power be utilized at the same time. This is one of the functions of the distribution system, which is discussed briefly below. (The equipments used to supply power in the external mode of the electric system are discussed briefly in a later portion of this chapter.)

Distribution System

Once the electric power has been generated and some of it transformed, it must be distributed to the various components and equipment where it is to be used. In a simple system, with comparatively few equipments and requiring only a single form of electric power, a simple distribution system could be used. In modern naval aircraft, however, with the complex electrical and electronic installations requiring many forms of power, an extremely complex distribution system is required.

Each model aircraft has different electrical requirements; therefore, each distribution system must differ from all others in accordance with individual requirements.

The major area of difference between distribution systems of different model aircraft lies in the switching arrangement used to change electric loads from one source to another in the event of a malfunction.

Long range patrol aircraft normally carry a flight engineer as part of its operating flight crew. The flight engineer is responsible for monitoring the operational status of many different systems within the aircraft. In some aircraft he is responsible for distributing individual electric loads among the various sources so as to provide for essentially balanced loads. He is usually responsible for recycling failed systems when it is assumed that the fault has been corrected. Interceptor and other carrier-based aircraft usually do not have a separate flight engineer. The distribution system for these two systems must be quite different in details, even though they may both incorporate all the basic requirements and capabilities for load distribution.

Power Conversion Devices

In most naval aircraft, the main electric power generation system produces 3-phase a-c power at 400 Hz. All aircraft require various levels and quantities of d-c power, and in many instances a-c power of a different frequency is also required. In these cases, various devices are needed to convert the power from the forms generated into the form required for the specific application. A few important conversion devices are discussed briefly in the following paragraphs.

TRANSFORMER-RECTIFIERS.—The most common conversion device for changing a-c to d-c is the transformer-rectifier. The 3-phase, 115-volt a.c. is reduced in a stepdown transformer and then rectified to produce the 28-volt d.c. required for operation of various relays, lights, instruments, mechanical devices, etc. Specific transformer-rectifier units are discussed in the electrical section of the Maintenance Instruction Manual for each model aircraft; the fundamental theory of transformers is discussed in Basic Electricity.

INVERTERS.—An inverter is a rotating electromechanical device used to convert low voltage d.c. into a.c. It consists essentially of a speed-governed d-c motor, an armature and brush assembly, and a permanent magnet inductor type a-c generator, all within a single unit. The armature and the permanent magnet rotor are usually mounted on a common shaft.

The inverter's output frequency and voltage should be checked periodically to assure that they are within prescribed limits. Should adjustment be required, the electrical shop is notified since adjustment of inverters is a responsibility of the AE rating.

FREQUENCY CHANGERS.—When a-c voltages of a frequency different from that produced by the main generator are required, suitable motor-generator combinations are used. Main electric power frequency is usually 400 Hz; many aircraft provide a 60-Hz source for test equipment and an 800-Hz source for certain instruments or components.

CIRCUIT PROTECTION AND CONTROL

The electric system of an aircraft is protected from damage and failure by fuses, current limiters, and circuit breakers. Control and distribution of power is accomplished by the use of switches and relays. Each of these components is available in many styles and sizes, some of which are ideally suited for use in aircraft while others are limited to use in shop installations. The following section presents a brief discussion of these components.

FUSES

Fuses provide a controlled, intentionally weakened link in an electric circuit. It serves as a safety device in the event of undesired overloads. Fuse sizes are available with ratings of a few milliamperes to several hundred amperes; fuses of most ratings are available for normal, slow-action or fast-action operation.

A fuse is a heat-sensitive, heat-operated device. When operated at rated current, it consumes electrical power and dissipates this power in the form of heat. Under normal operating conditions, the dissipated heat is not sufficient to cause the unit to fail; however, when the fuse is operated above the normal current rating, the overload current generates additional heat which melts the fusible element.

Voltage Rating

A fuse can be operated at any circuit voltage, if it is mounted in a sufficiently well-insulated holder (as long as the fusible element is able to fail without suffering arc damage). When a fuse fails due to excessive current, the full circuit voltage appears across the open fuse; if inductance is present in the circuit, a surge is generated which may cause a destructive arc to be formed within the fuse. Under these conditions, intense heat and pressure develop and the fuse may literally explode.

Fail-Time Characteristics

The fail-time characteristic of a fuse depends on the percent of rated current and the thermal inertia of the fuse. Overload currents (currents larger than the maximum value for which the fuse is rated) when flowing through a fuse, heat the element beyond normal capacity; after a period of time, the fusible element fails.

Fuse elements with a large thermal inertia increase the length of time before failure. Fuses containing such elements are known as slow-acting, slow-blow, or time-delay fuses. Slow-action fuses are constructed with a compound element; a thermal cutout and a fusible link that melts on short circuits or very high overloads. Small, light fuse elements reduce the thermal inertia and therefore are faster acting. This type of fuse is known as a fast-action fuse and is used principally for the protection of sensitive instruments.

In the selection of a fail-time characteristic, both the steady state and the transient or surge currents are considered. If currents of 200 to 400 percent of normal can be tolerated for periods of 1 to 10 seconds, a slow-acting fuse is specified. If the circuit requires immediate protection for any current above normal, a fast-acting fuse is specified. If the current must be limited to 200 percent of the rating for periods less than one second, then a normal, or medium, fail-time characteristic is specified. (See fig. 16-2.)

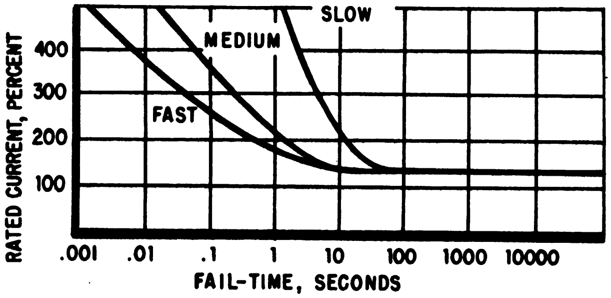

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Figure 16-2.—Fail-time characteristics of fuses.

When possible, a fuse should be operated at about 75 percent of its rated value; this provides a good balance between protection and reliability.

Vibration Resistance

Fuse protection for equipment subject to vibration can be provided by special vibration-resistant construction. This type of fuse has a spring formation, with winglike extensions which bear on the inside wall of the glass body, to decrease vibration of the fuse element. For slow-action fuses, a different construction, consisting of a compound spring and link structure, is used. On moderate overloads, as the compound element reaches the melting point, the spring pulls away from the link; on short circuits, the link fails.

Identification Coding

Fuses and their corresponding fuse holders are numbered according to a standardized system for easy identification. The numbering system is illustrated and explained in figure 16-3; some actual fuses are shown in figure 16-4.

Fuse Holders

The most common class of fuse holders used in Navy equipment is the post type holder shown in figure 16-4. It may be a screw-in or a bayonet type, both of which are securely

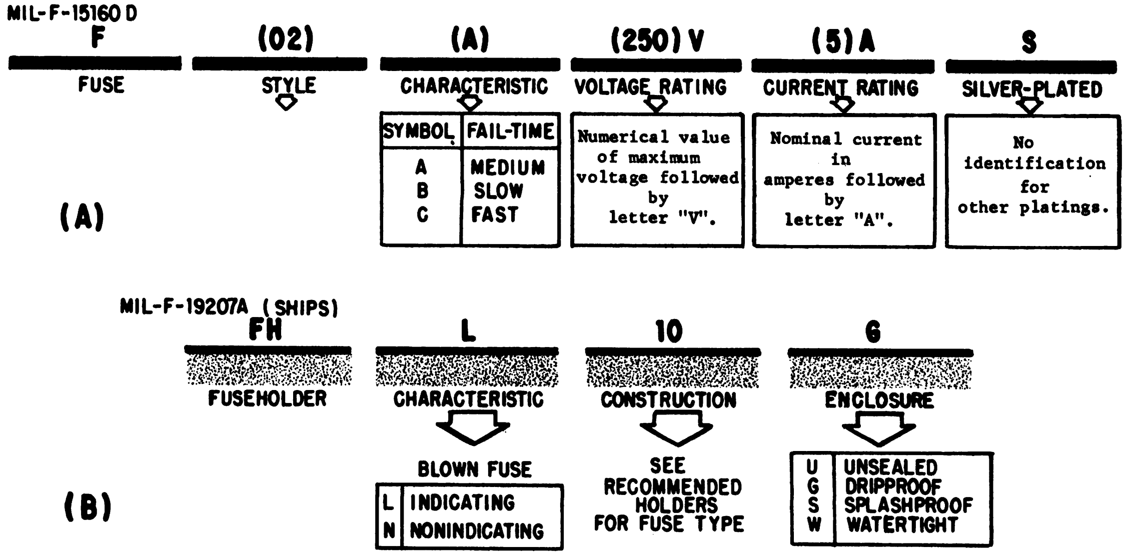

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Figure 16-3.—Identification coding. (A) Fuses; (B) fuse holders.

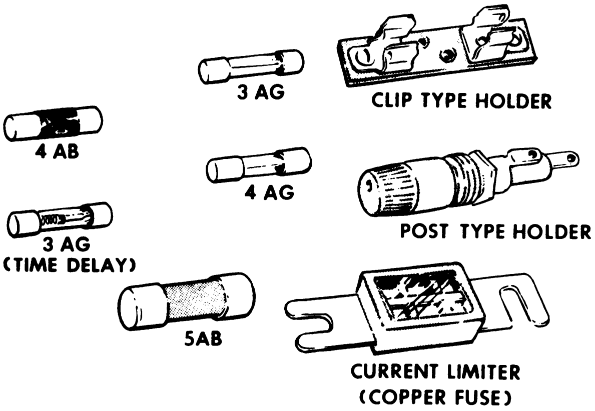

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Figure 16-4.—Aircraft fuses and fuse holders, typical examples.

mounted to the chassis or front panel of the equipment. The purpose of the holder is the same, regardless of type—to hold the fuse securely with good electrical connection and physical stability for protection from mechanical vibration and electrical short circuit.

Care should be used to insure that the fuse is of a physical size compatible with the holder. Fuses which are undersized allow physical movement and arcing, resulting in a blown fuse, erratic operation, or a damaged holder; fuses which are too large may cause cracking or breaking of the holder. Force should never be applied to either the fuse or the holder, since most are fragile devices.

Post type fuse holders are normally series-connected in the line, with the end connection to the power source and the center connection to the load. When connected in this fashion, the equipment is protected in the event of a broken holder—a short circuit from fuse holder to chassis ground will result in a blown fuse and excessive current will not flow. Reversed connections will not furnish this protection. Connection is normally made by solder connections, although some fuse holders are connected by use of the screw and lug method.

Current Limiters

Devices somewhat similar to fuses, called current limiters, are used in aircraft circuits that carry high currents. (See fig. 16-4.) The current limiter consists of a copper link of carefully predetermined sections. The sections melt when abnormally high currents start to flow. The melting sections have a high arc resistance to keep the circuit current within the capacity of the limiter. If the excessive current is only a temporary surge, the melting ceases and the circuit continues to operate as if no abnormal current had been present. Repeated applications of excessive current, or uninterrupted application for a period of several seconds, melt through the sections and cause the limiter to function in the same manner as a fuse.

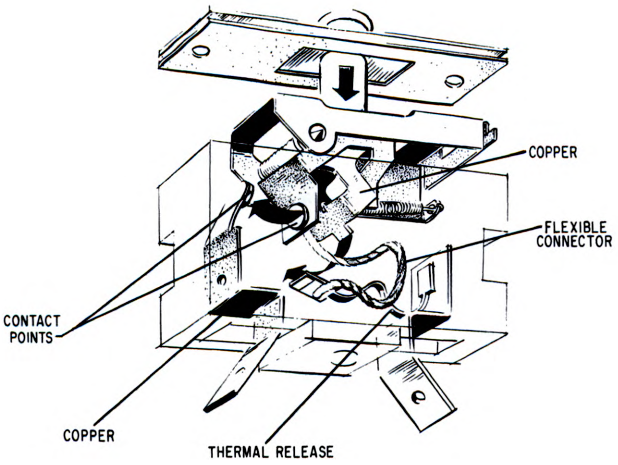
CIRCUIT BREAKERS

In modern naval aircraft, circuit breakers have replaced fuses as the main circuit protection device for most of the wires and cables making up the electrical system. The circuit breaker is designed to open the circuit under short-circuited or overload conditions without injury to itself. Thus, it performs the same function as the fuse, but has the advantage that it is capable of being reset and used again. Circuit breakers are rated in amperes and volts.

There are three basic types of circuit breakers (thermal, magnetic, and thermomagnetic), but the following discussion is directed mainly toward the thermal type because it is more generally used. Circuit breakers are divided into three categories—the pushbutton reset type, the toggle type, and the automatic reset type (sometimes called a circuit protector).

The pushbutton reset type consists of a bimetallic, thermally actuated, spring loaded device which connects two electrical contacts when set. This is shown in figure 16-5. An excessive current through the device causes an uneven expansion of the bimetallic mechanism (thermal release) which releases a trigger escapement and permits the spring loading to separate the contact members.

A visual indication of the automatic opening is provided by causing the pushbutton to move to an easily noticed "tripped" position. In this position the button is fully extended and the white ring plus the inner red section of the button is showing. The latest type of pushbutton breakers has a pullout feature which permits manual opening of the circuit.



AT.51
Figure 16-5.—Thermal circuit breaker.

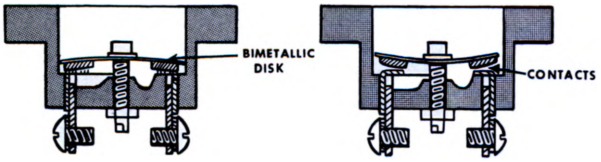
Another type of circuit breaker uses a toggle lever instead of the pushbutton. It operates in the same manner as the previously discussed breaker, with the exception that the tripped condition is indicated by the toggle lever being in the OFF position. This type of circuit breaker has the apparent advantage of also being usable as a switch.

Manual resetting of the circuit breaker may be accomplished by means of the actuator (either pushbutton or toggle lever) whenever the bimetallic thermal element cools sufficiently for the trigger to engage its latching mechanism. In connection with resetting, there are two classifications for circuit breakers; namely, trip-free and nontrip-free.

The nontrip-free circuit breakers can be prevented (by the operator's action) from tripping even though a tripping condition exists. This should be done only in an emergency; since this action is apt to change the calibration, the breaker should be replaced as soon as conditions permit. This type breaker is no longer being installed in new aircraft; however, it is still found on some older models.

In the trip-free class, the contacts cannot be kept closed by holding the actuator in the closed (or reset) position as long as an overload condition persists which would otherwise cause normal tripping.

A disk type thermal circuit breaker is shown in figure 16-6. This breaker consists of a conductive bimetallic snap-acting disk which bridges two electrical contacts. When this disk is heated by the excess current through it, it snaps to the reverse position, opening the contacts and breaking the circuit. In circuit breakers having low ratings, a resistance wire is inserted; current through this wire provides the heat necessary to snap the disk. These breakers are reset by pressing a button, restoring the disk to its original position. When circuit breakers of this type are closed, they cannot be reopened manually. They are also nonindicating; that is, the position of the breaker (open or closed) cannot be determined by visual inspection.



AT.52
Figure 16-6.—Thermal circuit breaker (disk type).

The automatic reset type circuit breaker is similar to the bimetallic disk type just described, except that it has no reset pushbutton; it resets itself automatically. After a short time, when the disk has cooled sufficiently, it will bend back and close the circuit, resetting itself. If a constant overload exists, the breaker will intermittently break the circuit.

Another type of circuit breaker is the switch toggle variety based on magnetic instead of thermal operation. This type can be made to open almost instantly when more than the rated current flows in the circuit. An electromagnet is placed in series with the spring-loaded contacts, and the contacts are mounted so that an armature acts as a latch to hold them closed. When an excess current flows, the armature is pulled toward the electromagnet, releasing the contacts and opening the circuit. To reset the circuit breaker, the contacts are closed manually and the spring-loaded armature returns to its normal position.

AUXILIARY POWER SOURCES

The electric power requirements for starting and servicing modern aircraft are very high. Even in those aircraft which have batteries installed, routine servicing and operational testing of the electronics system require that either the aircraft engines be operating or that an external source of electric power be used.

There are many auxiliary power units (APU's) available for supplying electric power to the aircraft for engine starting, ground servicing, and operational testing. External power receptacles are mounted on all aircraft to provide a means of connecting the external sources to the aircraft.

Some aircraft are also furnished with an airborne auxiliary powerplant (APP) installed aboard or attached externally to the aircraft. The auxiliary powerplant usually consists of an independently operated gasoline engine or turbine which drives a generator. The generator supplies power to the electric system on the ground and in the air. Although the airborne auxiliary powerplant is not capable of supplying the entire load requirements for normal operation of all equipment, it does have the capacity to furnish limited loads for ground servicing or for emergency use in flight.

This section presents a brief discussion of ground- and ship-based auxiliary power units, airborne auxiliary powerplants, and the main power sources normally found in aircraft hangars and on carrier flight decks.

AUXILIARY POWER UNITS

In this discussion the term auxiliary power unit is limited to those units which are portable, but are not installed aboard the aircraft. The units may be self-propelled, towable, or merely transportable; they may use diesel fuel, jet fuel, or gasoline. The generators may be driven by the unit's engine or it may have its own prime mover. Several types are discussed; however, before beginning a discussion of specific types of individual models, several generalizations should be mentioned.

When moving the APU into the vicinity of the aircraft, care should be taken to avoid collision with aircraft or other equipment. Flight lines and aircraft parking areas are normally crowded, and space between aircraft and equipment may not be sufficient to allow passage of the APU. Equipment and/or aircraft may have to be moved and repositioned to permit access to the aircraft to be serviced. When movement of the aircraft is necessary, the line crew should be notified, and requirements should be outlined. Local procedures and policies must be followed, and line safety regulations observed. Under NO conditions should the APU be used to move the aircraft, not even "a couple of feet."

Once access to the aircraft has been gained, the APU must be connected to the aircraft. Each unit has its own procedures for operation, but some general considerations apply to all. Prior to connecting the APU to the aircraft to be serviced, all aircraft power switches should be checked and placed in the proper position. (This requires familiarization with the aircraft; the information is available in the Flight Manual and in the Maintenance Instructions Manual for each model aircraft.)

Prior to making the actual connection, the cable and the receptacle should be inspected carefully for general condition and for correct polarity/phase. Many flights are aborted because external power cables have been inserted into aircraft with polarity or phase reversed due to careless insertion or defective cables.

The APU should not be connected to the aircraft with a "hot line"; the generator power switches should be off. After connection, the generator may be activated, and the switches turned on when stable operation is obtained.

During high load operation of APU's, the power cables frequently heat excessively and the cable voltage drop is quite noticeable. Nearly all of the mobile electric power plants (MEPP's) have an output current capability well in excess of the current rating of the cables. Therefore, when supplying power to large loads, the current ratings of the cables must be considered. If the load requirements exceed the rating of the cable, the load should be reduced or an APU with a higher capacity cable should be obtained.

Mobile Electric Powerplants

NC-10 AND NC-10A.—The NC-10 and NC-10A powerplants are diesel engine-driven mobile powerplants, designed to supply 90 kva at 115/200 volts, 3-phase, 400/Hz for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the generated electric power is rectified to supply 28 volts d.c. at

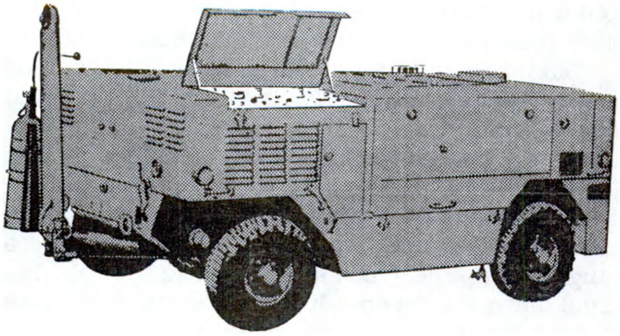
750 amperes (1,000 amperes intermittent) for aircraft starting.

The powerplant is enclosed in a steel housing, fabricated in two sections which are easily removed for servicing of the unit. Operating components are mounted on a four-wheel trailer, which is equipped with mechanical type internal expanding front wheel brakes. The brakes may be set by a hand lever or automatically set when the tow bar is in the vertical position.

Double hinged doors provide access to the control panel, starting components, and three output power cables.

The plant's electrical system is protected from overload by output circuit contactors, circuit breakers, over- and under-voltage relays, over- and under-frequency relays, thermal overload relays, and fuses.

The NC-10 powerplant was designed for use on carriers and shore stations. The NC-10A (fig. 16-7) was especially designed for Marine Corps shore duty activities. The operating features and technical data are the same for both plants, except that the NC-10A employs a self-propelled feature, requiring a licensed operator/driver. The NC-10A is not to be used as an A/C towing vehicle.



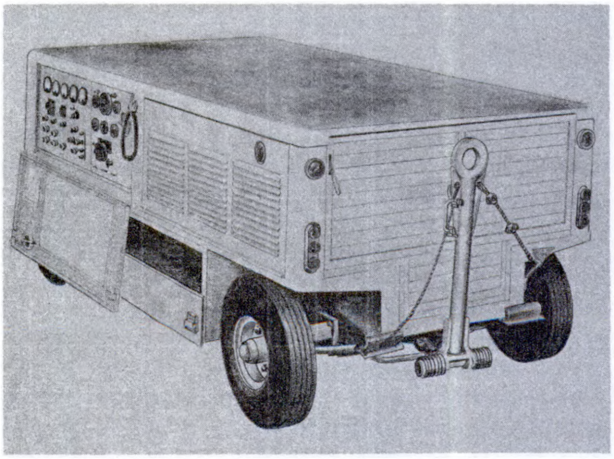
AT.60

Figure 16-7.—Mobile Electric Powerplant Type NC-10A.

NC-12 AND NC-12A.—The NC-12 and NC-12A are diesel engine-driven powerplants, designed to supply 125 kva at 115/200 volts, 3-phase, 400 Hz for servicing, starting, and maintaining helicopters and jet aircraft. A portion of the generated electric power is rectified to supply 28 volts d.c. at 750 amperes (1,000 amperes intermittent) for aircraft starting. These units utilize dual power output circuits which make them capable of simultaneously delivering electric power for two P-3A aircraft.

The powerplants and components are mounted on a four-wheel trailer, equipped with mechanical front wheel brakes which are actuated by a hand lever or the spring-loaded tow bar. These units do not come equipped with self-propelled features; they must be towed.

The NC-12 and NC-12A are similar except the NC-12 was designed for shore duty operation, while the NC-12A was designed for either carrier or shore-based use. The electrical characteristics are identical. Figure 16-8 depicts the NC-12A.



AT.61

Figure 16-8.—Mobile Electric Powerplant Type NC-12A.

The AQ will come in contact with many new types of powerplants such as the NC-10 series and NC-12 series, which will eventually replace the older plants such as the NC-5, NC-6, and NC-7 series.

(NOTE: Most naval air stations and activities have training courses available to provide instruction in the use and operation of mobile powerplants.)

Table 16-1 shows a comparison of the major characteristics of the mobile electric powerplants discussed in the preceding paragraphs, as well as some older types still in common usage.

Table 16-1.—Characteristics of mobile electric powerplants.

Type	Methods of propulsion	Generator drive	Operating environment	Power ratings		Starting Power		Service power	
				d. c.	a. c.	Jet	Recip.	Jet	Recip.
NC-5, NC-5A, NC-5B	Self-propelled gasoline engine vehicle	Main vehicle engine	Shore based only	28/35v 200/500a 1000a int	115/200v 400 Hz, 3Ø 30/45 kva	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-6, NC-6A	Towed trailer	Gasoline engine	Shore based only	28.5v 200a 32/45 kw	120/208v 400 Hz, 3Ø 30 kva	DNA	DNA	a. c. d. c.	a. c. d. c.
NC-7, NC-7A, NC-7B, NC-7C	Towed trailer, or self-propelled within narrow limits	Gasoline engine	Shore based only	28.5v 750a 1000a int 45 kw	115/200v 400 Hz, 3Ø 35 kva 0.75 PF	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-10	Towed trailer	Diesel engine	Shore or carrier based	28v 750a 1000a int	115/200v 400 Hz 90 kva	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-10A	Towed trailer or self-propelled	(same)	(same)	(same)	(same)	(same)	(same)	(same)	(same)
NC-12	Towed trailer	Diesel engine	Shore based only	28v 750a 1000a int 45 kw	115/200v 400 Hz 125 kva	d. c. only	d. c. only	a. c. d. c.	a. c. d. c.
NC-12A	(same)	(same)	Shore or carrier based	(same)	(same)	(same)	(same)	(same)	(same)

AIRBORNE AUXILIARY POWERPLANTS

Some of the larger aircraft are equipped with auxiliary powerplants installed at different locations on different aircraft. They are used to furnish electric power when engine-driven generators are not operating or when external power is not available. The APP is utilized to furnish power since excessive battery usage must be avoided.

Another particular application for the powerplants is in large land-based aircraft. Here they are used to provide a constant voltage at a constant frequency. This is advantageous because the output of the APP is not dependent on aircraft engine rpm.

Some of these units use a gasoline engine to drive the generator, while others use a gas turbine. Figure 16-9 (A) shows a gasoline engine-driven APP; figure 16-9 (B) shows a gas turbine type.

Auxiliary powerplant logbooks must be kept on each powerplant. The operator of the powerplant is responsible for entering the operating time in the log each time the powerplant is used.

RECTIFIER UNITS

The use of a-c generators for primary electrical power in modern naval aircraft has been mentioned previously. One of the reasons for this is the saving in weight.

The size of wire required to deliver a given wattage can be considerably smaller, if the voltage is 115 volts a.c. rather than 27.7 volts d.c. Due to higher voltage and a four-wire (grounded neutral) system, the current carried in each wire is only a fraction of that required for the same power in a 28-volt d-c system. This permits the use of much smaller aircraft wiring with a great saving in weight. The a-c generator itself, especially in the larger sizes, is lighter than a d-c generator of comparable output. Many of the components for system control and protection are also lighter than comparable d-c components.

Even though the d-c generator is eliminated by the utilization of a.c. as a primary source of power, d-c voltages are required for proper functioning of many systems. This d-c voltage is obtained from a transformer-rectifier assembly.

Figure 16-10 is a schematic drawing of a transformer-rectifier unit. The transformer is a 3-phase, 400 Hz, stepdown type. The input is 115 volts a.c. to a delta connection, and the output is 22 volts a.c. across each leg of a wye connection. The rectifiers are of the selenium dry disk type, forming a bridge unit. After rectification (and minus the voltage drop across the rectifier), the output is 28 volts d.c. (Refer to chapter 16 of Basic Electricity for discussion of 3-phase power components.)

DECKEDGE POWER

The primary function of the deckedge electrical power system installed on aircraft carriers is to provide a readily accessible source of servicing and starting power to aircraft at almost all locations on the carrier's flight and hangar decks.

The 28-volt d.c. is supplied by motor-generators or rectified a.c. from remote a-c generators.

The 400-Hz, 3-phase a-c servicing voltage is usually supplied by these same a-c generators through stepdown transformers. Figure 16-11 shows a diagram of an electrical system which may be found on a modern carrier. The deckedge power may be supplied by service outlets at the edge of the flight deck or from recesses in the flight deck. All systems have standard remote control switches, service outlet boxes, and portable cables. Figure 16-12 shows a typical deckedge installation.

Although there are some variations between carriers of different classes and aircraft of different models, this discussion and the associated figures represent a typical example. For explicit details concerning a specific installation, check the deckedge station and its power cables.

The d-c service outlet box contains two male plugs. One is rectangular in shape and the other is oval. The rectangular plug provides servicing power and the oval plug provides starting power for aircraft with electrical starters.

The aircraft is equipped with an oval-shaped plug for applying d-c servicing power and a rectangular-shaped six-pin plug for applying 3-phase, 400 Hz, a-c servicing power. Power is applied to the aircraft by connecting the portable cables between the deckedge and aircraft plugs. The ends of the a-c portable cable are interchangeable; however, the ends of the d-c portable cable are not.

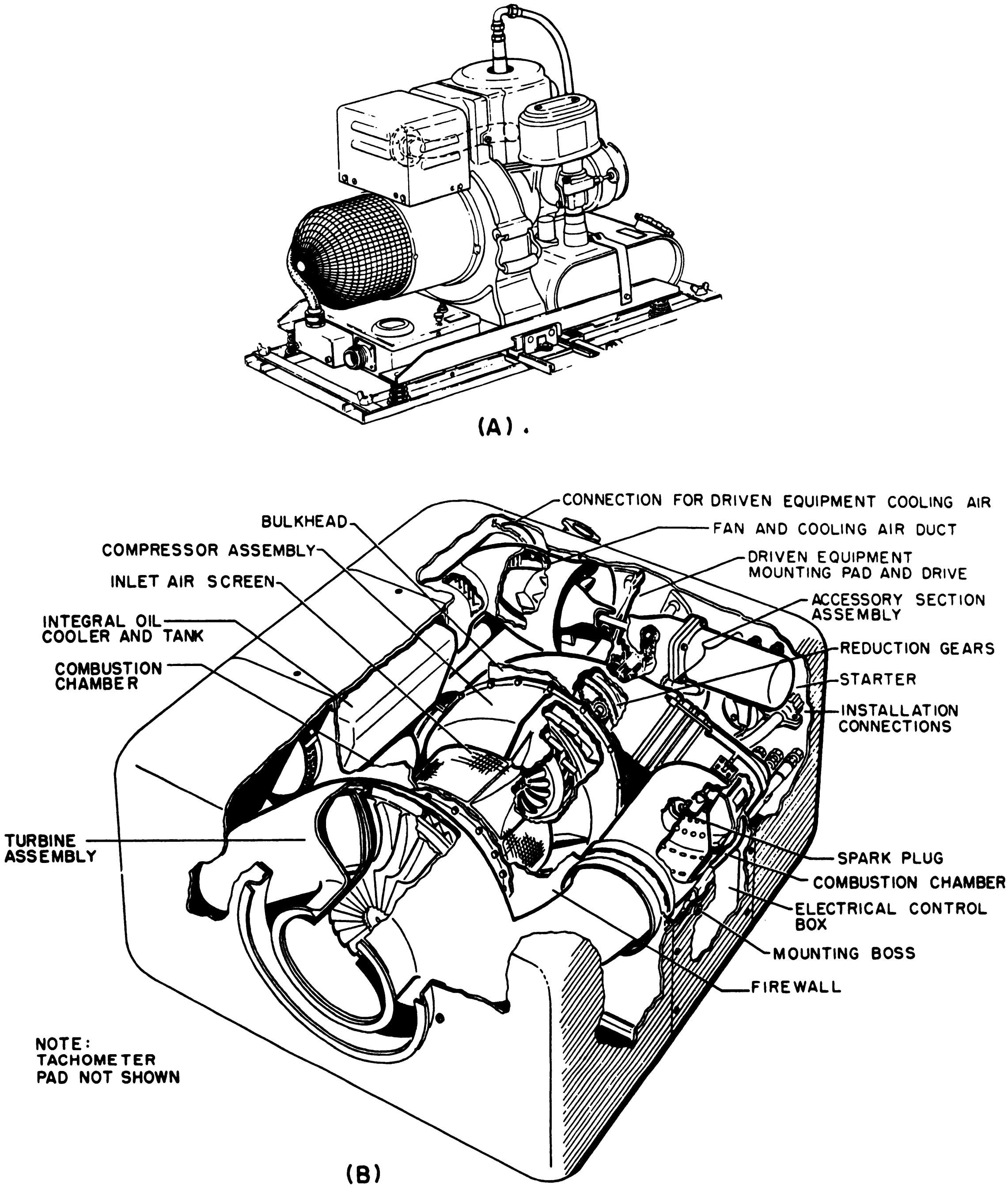


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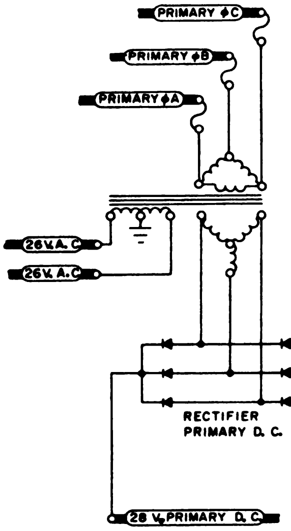
Figure 16-9.—(A) Gasoline engine driven APP; (B) gas turbine type APP.



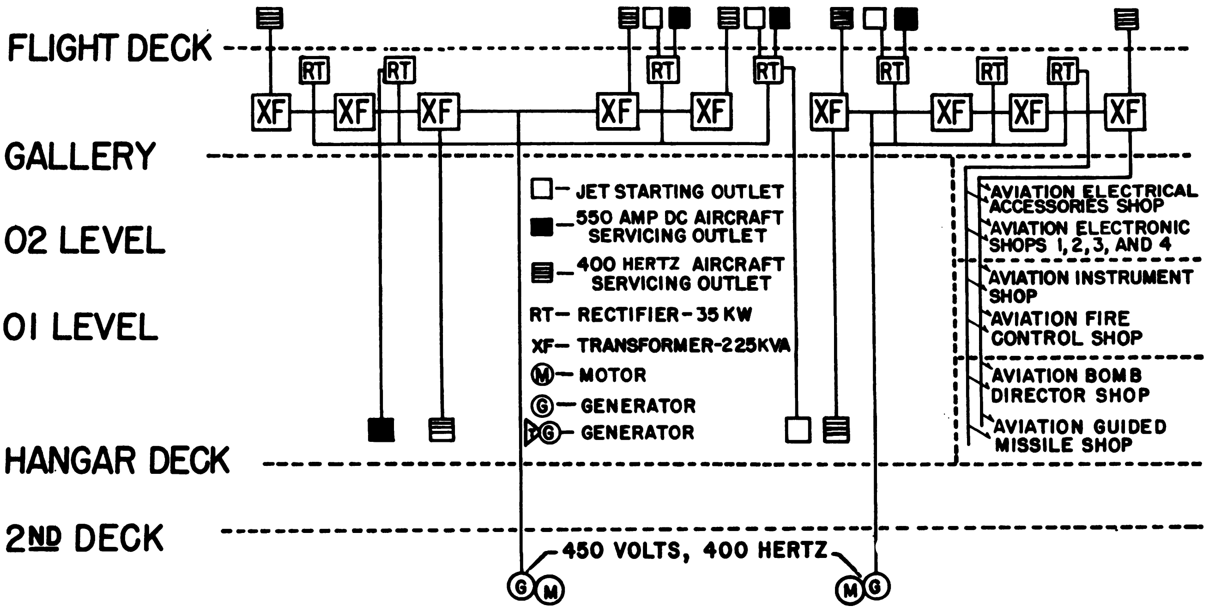
AT.64
Figure 16-10.—Transformer rectifier.

The a-c service power is usually provided at the same station as the d-c power. The cable is usually permanently attached to the service outlet box. Although its plug is rectangular, there is no danger of connecting it to the d-c service power receptacle as the size and number of pins are not the same.

Care should be exercised when connecting auxiliary power cables to the aircraft. The cables are heavy, and damage to the aircraft may result if there is not sufficient slack in the cables.

GROUND COOLING EQUIPMENT

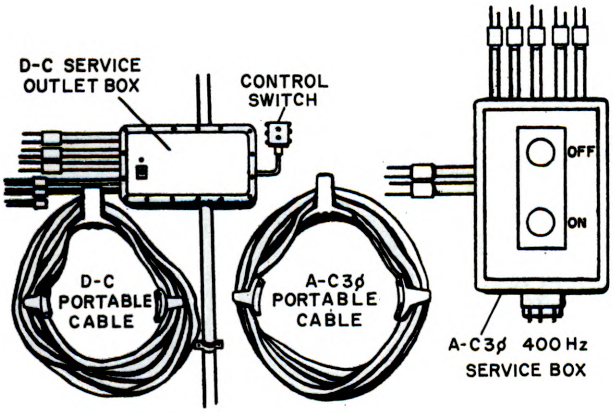
The purpose and need for ground cooling will vary with type of aircraft and climatic conditions. When repairing high-voltage equipment aboard large aircraft in a tropic zone, ground cooling of the aircraft cabin reduces the hazard of shock due to clothing being wet with perspiration. It may also prevent shorting of components by falling perspiration.


FLIGHT DECK
GALLERY
02 LEVEL
01 LEVEL
HANGAR DECK
2ND DECK
RT
XF
☐— JET STARTING OUTLET
■— 550 AMP DC AIRCRAFT SERVICING OUTLET
▤— 400 HERTZ AIRCRAFT SERVICING OUTLET
RT— RECTIFIER-35 KW
XF— TRANSFORMER-225KVA
Ⓜ— MOTOR
Ⓖ— GENERATOR
Ⓖ— GENERATOR
AVIATION ELECTRICAL ACCESSORIES SHOP
AVIATION ELECTRONIC SHOPS 1, 2, 3, AND 4
AVIATION INSTRUMENT SHOP
AVIATION FIRE CONTROL SHOP
AVIATION BOMB DIRECTOR SHOP
AVIATION GUIDED MISSILE SHOP
450 VOLTS, 400 HERTZ
G
M
M
G

AT.65
Figure 16-11.—Deckedge electrical system.

Figure 16-13 illustrates how these connections may be made. To obtain d-c servicing power to the aircraft, connect the cable from A to A'; to obtain a-c service power connect it from B to B'.

A primary reason for using ground cooling equipment, even in temperate zones, is the fact that electronic equipment produces large quantities of heat. This heat must be dissipated or the equipment would achieve temperatures



AT.66

Figure 16-12.—Typical deckedge installation.

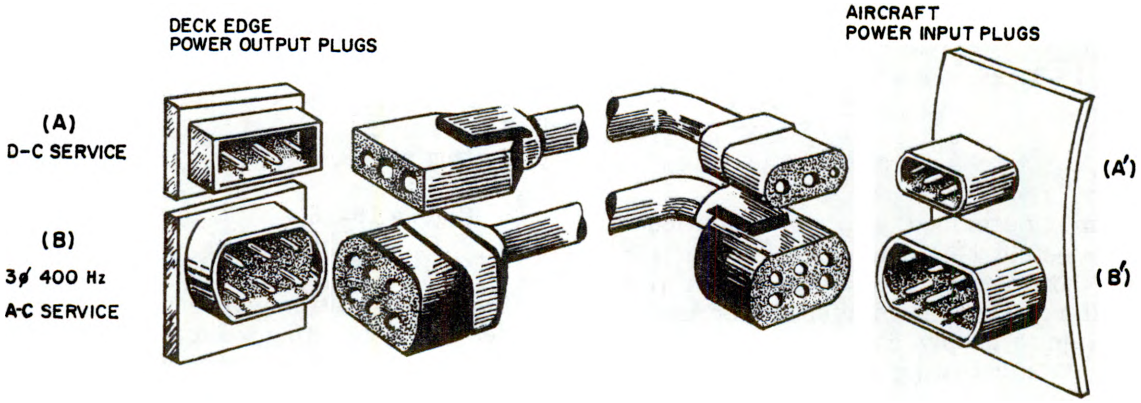
that could cause damage and create a fire hazard.

When the aircraft is airborne, various means are used to accomplish the required cooling. Some electronic equipments have fans built in for cooling. Others generate so much heat that a blast of air from outside the aircraft must be used. Some large magnetrons are liquid cooled—the liquid, in turn, is cooled by air directed over a radiator.

When a large quantity of air is required for cooling, a common source for the air is the aircraft's ventilation system. However, line maintenance, ground operational checks, and functional checks are usually performed without the aircraft's ventilation system operating, since this system is driven by the aircraft engines. Therefore, a substitute air supply must be provided for the air distribution system.

The NR-2 is a mobile air conditioner (fig. 16-14) designed for ventilating and cooling aircraft cabins and electronic equipment compartments. The NR-2 air conditioner provides cool, moisture-free air with an ambient temperature range of 50°F to 100°F; it is capable of delivering 30 pounds per minute of 50°F cool air with a maximum relative humidity of 90 percent at the end of 30 feet of 4-inch diameter flexible hose.

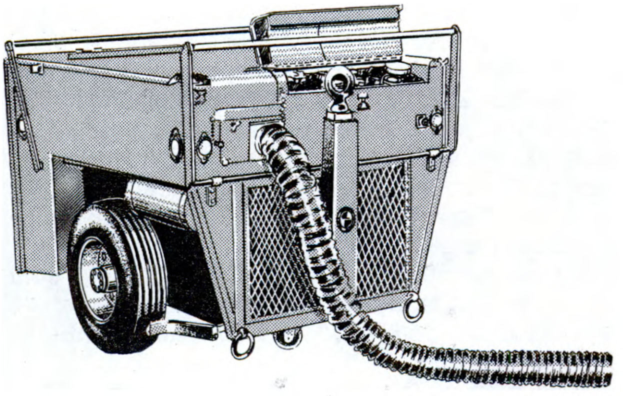
The trailer is of welded steel construction. Access doors are provided for full accessibility. The undercarriage provides two-wheel coil spring suspension on the transverse centerline of the unit and is mounted on pneumatic wheels. Two swivel casters are provided on the longitudinal centerline at each end of the unit. A mechanism, actuated by a two-position lever, raises and lowers the caster in unison. When vehicle towing of the unit is desired, the casters are raised to provide deck clearance. The casters are lowered to stabilize the unit in a level position for operation or hand maneuvering. A spring-loaded brake arrangement is incorporated to prevent an unmanned unit from rolling free.


DECK EDGE POWER OUTPUT PLUGS
AIRCRAFT POWER INPUT PLUGS
(A) D-C SERVICE
(B) 3ϕ 400 Hz A-C SERVICE
(A')
(B')

AT.67

Figure 16-13.—D-c and a-c power cables and plugs.

The brakes are released when either or both of the control bars are pressed toward the



AQ.580

Figure 16-14.—NR-2 air conditioner.

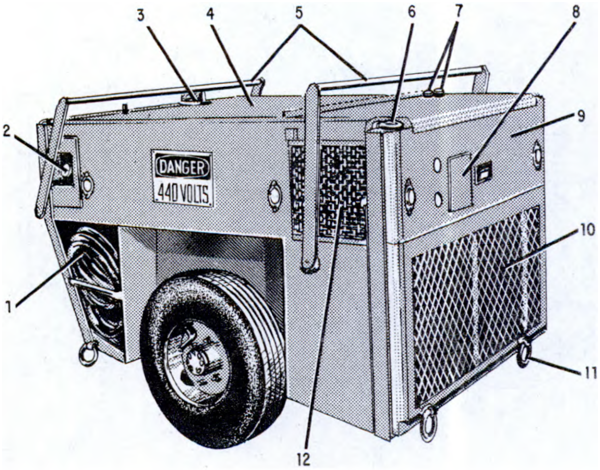
center of the trailer. Before a unit can be towed, it is necessary to lock the brakes out by setting the brake locking device. The lower frame of the trailer is equipped with four tie-down rings, and four rings are provided in the top for lifting.

Figure 16-15 displays all the unit features of the NR-2.

KOKA 567A

This unit, described as "air conditioner, portable electric," is basically an electric-driven air-conditioning unit mounted on a four-wheel trailer. The unit is intended for use on the flight line to supply cooling air to aircraft during electronic testing or other operational testing.

With a refrigerating capacity of 31.2 tons, the unit uses an 8-cylinder compressor driven by a 60-hp, 440-volt, 3-phase, 60-hertz motor to deliver a maximum of 3,500 cfm of air at a minimum temperature of 45°F. This airflow may be varied by means of a manual damper located in the supply air outlet. Adjustment to requirements can be made by the operator and airflow readings of pressure and volume can be read directly at the instrument panel. An automatic temperature control device will maintain the leaving-air temperature (at the setting of a thermostat with a range of 0° to 120°F, located on the control panel) by varying the volume damper to control airflow. This feature permits maintaining constant air temperature with a slight variation of supply airflow.



AQ.581

1. Power cable (stored).
2. Circuit breaker.
3. Brake latch (brakes released).
4. Service door (hose storage).
5. Push bars.
6. Lifting ring.
7. Personnel taps.
8. Service access panel.
9. Evaporator coil.
10. Condenser coil.
11. Tiedown ring.
12. Supply air filter.

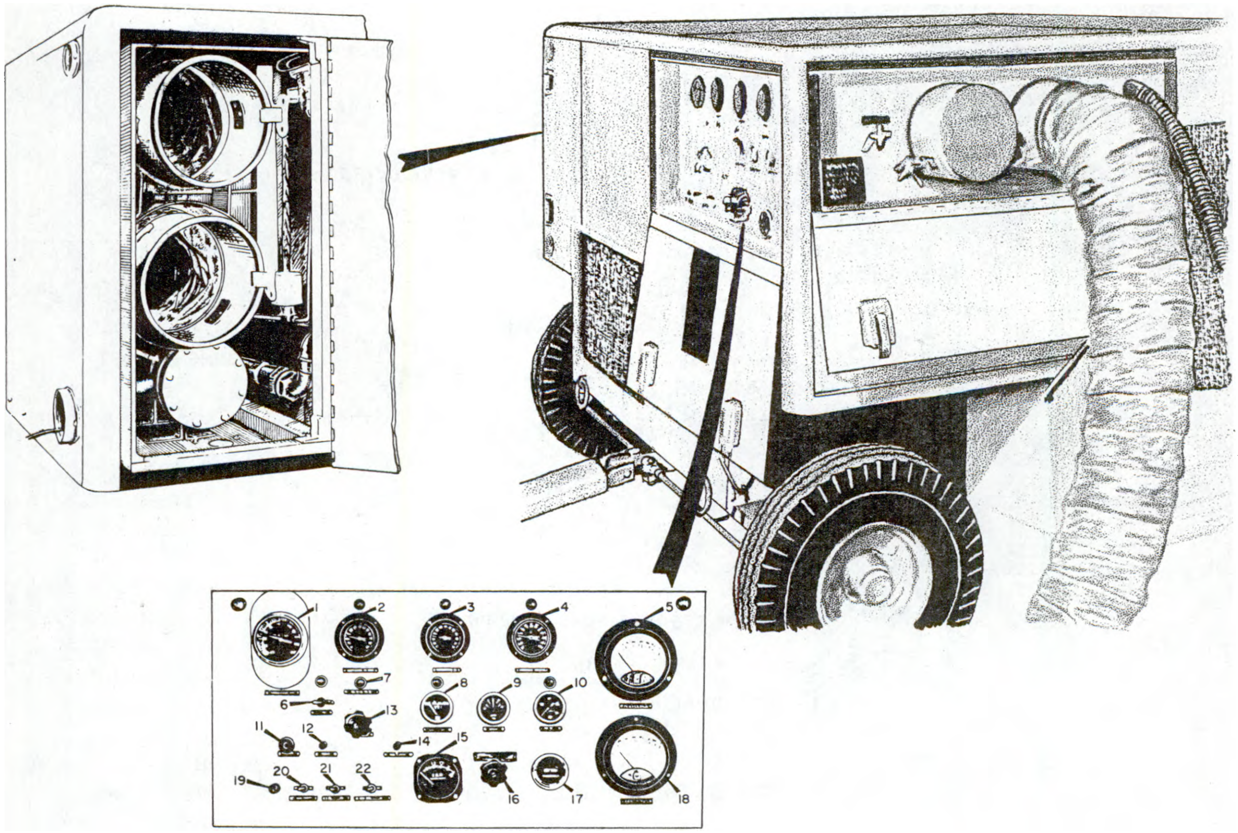
Figure 16-15.—NR-2 air conditioner unit features.

The refrigeration unit is automatically prevented from operating when the outside ambient air temperature is less than 40°F.

NR-3

The NR-3 is a trailer-mounted, Freon cycle, 120-hp, engine-driven mobile air-conditioning unit. (See fig. 16-16.) This unit is completely self-sustaining and carries enough fuel and water to provide 4 hours of continuous operation. A lunette eye, with a shock control device, is attached to the end of a steerable tow bar and will allow the air conditioner to be towed up to speeds of 40 mph on paved surfaces. A tow bar retainer allows the tow bar to be stowed in the vertical position when not in use. A parking brake provides a means of securing the fully loaded unit on grades up to 35 percent.

This air-conditioning unit supplies cool, moisture-free air to the cabin conditioning and cooling equipment systems during ground



AT.72

Figure 16-16.—NR-3 air conditioner.

checkout and testing of an aircraft's various systems. The unit is capable of delivering 294,000 Btu (24.5 tons gross) of conditioned air. This produces 100 pounds of airflow, at a pressure of 3 pounds per square inch, throughout a range in ambient temperatures from 10°C (50°F) to 43°C (113°F) when measured at sea level. The equipment is designed to operate at altitudes up to 5,000 feet above sea level.

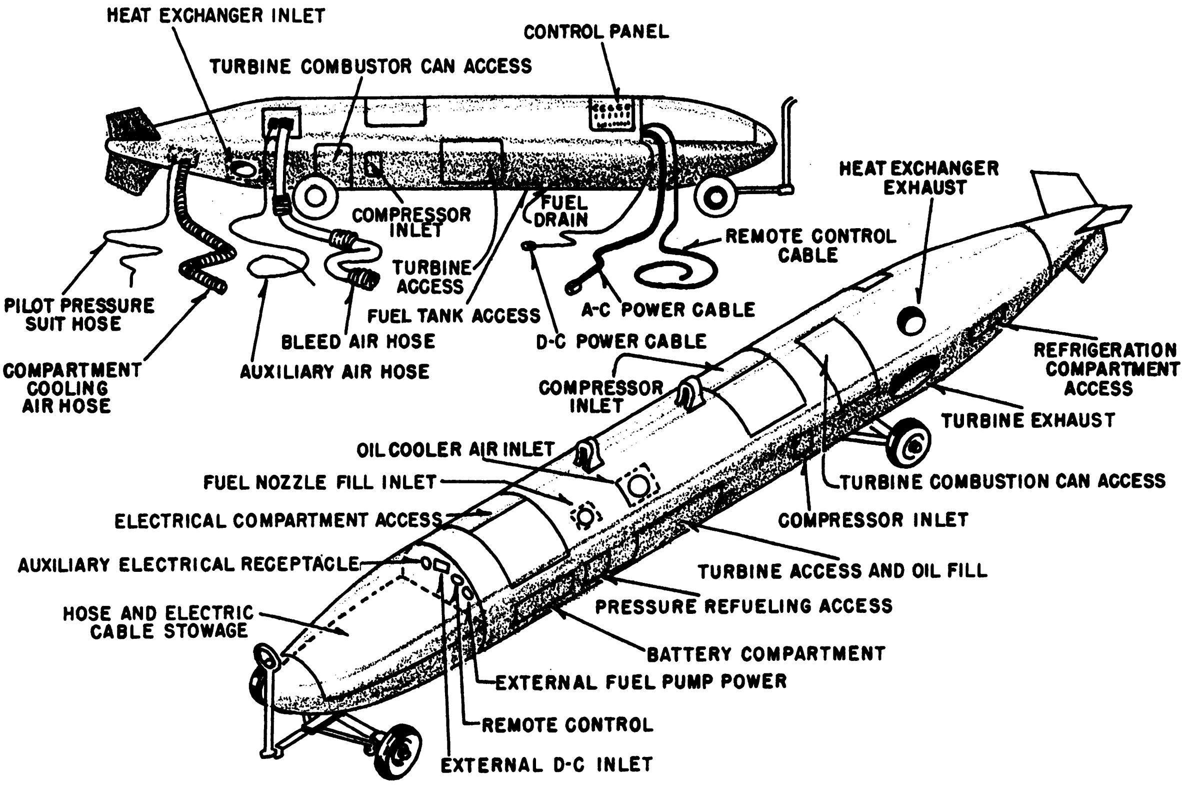
MULTIPLE PURPOSE UNITS

SERVICING UNIT CP 105

The AiResearch CP 105 is a gas turbine-driven power and refrigeration aircraft ground support unit furnished to the Navy in three different configurations. It is used primarily in support of the RA5C and F4J aircraft. All three arrangements employ basically the same system, using a small gas turbine to supply electric power and air for refrigeration, main aircraft engine starting, and pilot suit pressurization.

(NOTE: Electric power is generated by an air-driven turbine.)

The RCPP 105 (one of the three available models) is mounted in a 22-foot long aerodynamic pod for air transportation as an aircraft external store. On the RA5C, the pod is transported under the wing; on the F4J, it is carried under the fuselage. A cradle type towable trailer is provided for ground movement of the unit. (See fig. 16-17.)



AT.73

Figure 16-17.—RCPP-105, showing external connections.

The RCPT 105 is mounted in a self-propelled, low-silhouette (38 inches from the ground) trailer.

The tractor unit is similar to the RCPT 105 except that the turbine-driven unit is mounted on a diesel tractor.

COLLING-PUMPING UNIT AN/AWA-6

The AN/AWA-6 (fig. 16-18) is a specialized unit designed for making operational checks of the AMCS in the F-4B. It supplies cooling air, electrical power, and hydraulic power to the aircraft. This makes it convenient for the AQ to make operational checks of the Aero 1A system. The unit is electrically powered, which necessitates having electrical outlets or a power unit near the aircraft. As can be seen, this unit is quite small and can be easily handled by one man in confined spaces such as aboard an aircraft carrier.

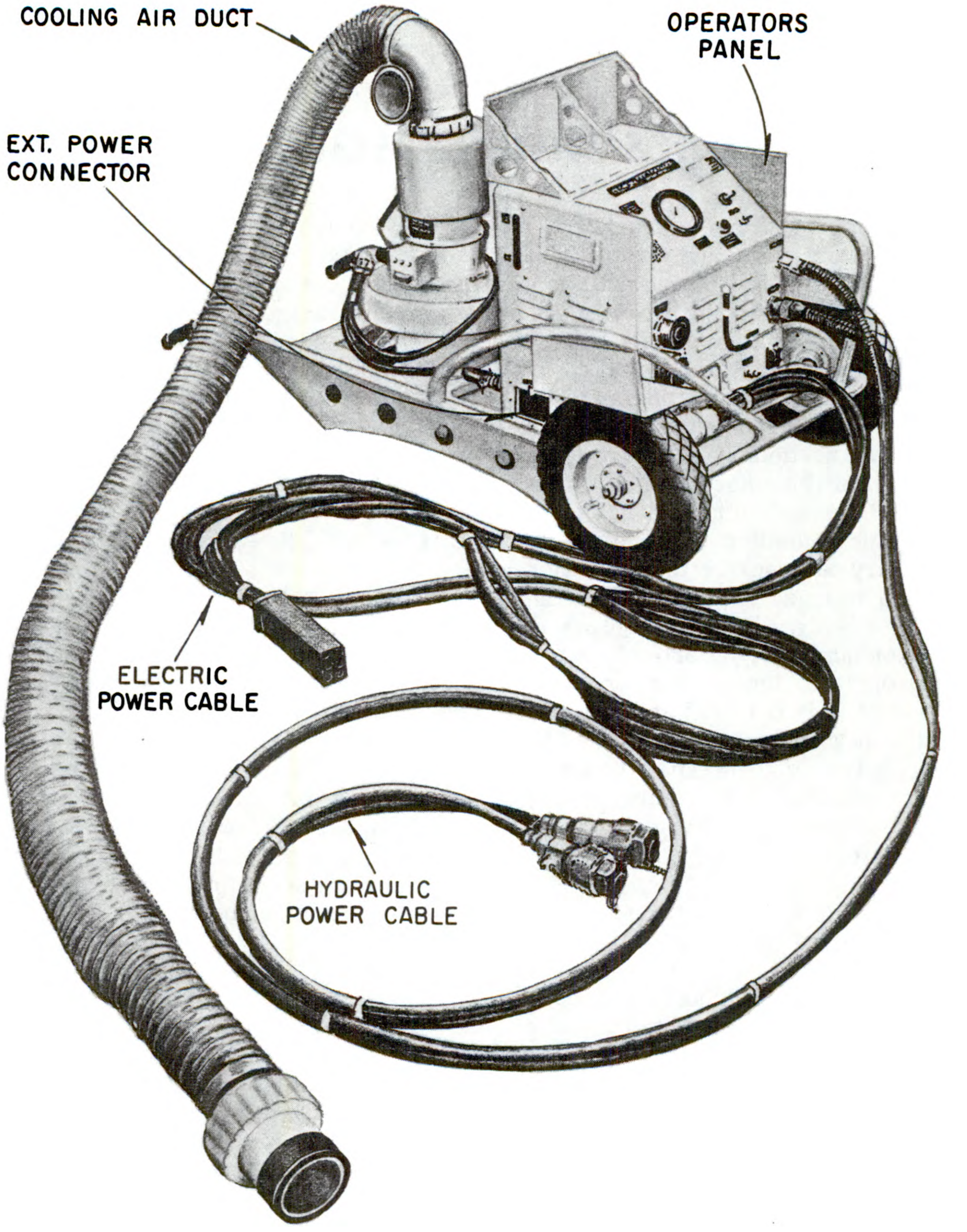


Figure 16-18.—Cooling Pumping Unit AN/AWA-6.

CHAPTER 17

AVIONICS SUPPORT EQUIPMENT

Preceding chapters of this manual have presented the basic principles and concepts of some of the equipment the technician will encounter. An understanding of the theory of operation of these equipments forms only a portion of the knowledge necessary to successfully perform the maintenance tasks required. A thorough knowledge of electrical and electronic test equipment is also needed.

The test equipments discussed in this chapter are typical of the ones currently in use in the fleet. No attempt is made to include theory beyond that necessary to describe the operation of the test set under discussion. Whenever the technician must use a piece of test equipment with which he is not familiar, he should always consult the appropriate instruction manual. These publications contain detailed and specific information on the particular equipment. The purpose of this chapter is to discuss some of the different test equipments from the standpoints of operation and general operational and maintenance procedures.

CARE AND USE OF AVIONICS SUPPORT EQUIPMENT

All electronic maintenance shops are provided with a variety of test equipment to be used in maintaining the many different types of electronic units it supports. However, there are very few spare test sets. When a test set becomes inoperative, shop maintenance suffers. Therefore, every man must use the test equipment only for the purposes and in the manner for which it was designed. Protect the equipment from physical harm that may result from dropping, falling, or any other careless misuse, and always observe proper operating techniques.

One of the chief causes of test set failure is carelessness. The user can be careless in operating procedure or in handling the set. The usual carelessness in operating procedure is improper selection of range for the quantity to be measured, such as attempting to measure 250 volts on the 50-volt scale of a meter. If there is any doubt about proper usage of a test set, it is wise to refer to the manual issued with the set.

Much damage to test equipment results from improper handling. Technicians often place test sets near the edge of the bench where they can easily be knocked off or pulled off by the test leads. Read the instructions for proper handling and operating procedure, and think while using the equipment.

CALIBRATION

Test sets require checks to determine if they are within operating tolerances. Some test sets are used as frequency standards and require periodic calibration. In every case the recommendations of the manual or pamphlet issued with the set should be followed, unless those recommendations have been changed by current instructions.

Calibration is normally performed in a shop that is equipped with special purpose test sets. It is seldom accomplished at the organizational level of maintenance.

REPAIR

When calibration of the set is not involved, minor repair of test sets is often accomplished at the level of maintenance at which the test set is used. Repairs are usually limited to replacement of test leads and fuses. Current instruction on repair of test equipment should be consulted before attempting any repairs of a major nature.

HANDLING PRECAUTIONS

Some equipments may require special handling; however, there are several precautions which apply to test equipments in general. Rough handling, moisture, and dust all affect the useful life of such devices. Bumping or dropping a test instrument, for example, may destroy the calibration of a meter or short circuit the elements of an electronic tube within the instrument. Creasing or denting coaxial test cables will alter their attenuating effect, thereby affecting the accuracy of any RF measurements made with these cables in the circuit.

To reduce the danger of corrosion to untreated parts, always store test equipment in a dry place when it is not in use. Excessive dust and grime inside a test equipment also affects its accuracy. Be sure that all the assembly screws which hold the case of the test equipment in place are tightened securely. As an added precaution, all dust covers should be placed on test equipments when they are not in use.

Meters are the most delicate parts of test equipments. In order to insure that the meter will maintain its accuracy, these additional precautions should be followed:

1. Make certain that the amplitude of the input signal under test is within the range of the meter.
2. Keep meters as far away as possible from strong magnets.
3. When servicing an item of electronic equipment which contains a meter, disconnect the meter from the circuit before making resistance or continuity tests.

(The latter precaution will eliminate the possibility of burning out the meter.)

The instructions for properly stowing test equipment cables and other accessories, as set forth in the instruction manuals accompanying the equipment, should be carefully read and strictly followed. Improper stowage of accessories results in changes in cable characteristics, intermittent shorts in cables and leads, and, in general, causes unreliable test equipment indications.

MEASURING INSTRUMENTS

The term "measuring instruments," as used in this discussion, includes only that class of test equipments which measure the basic parameters of an electronic equipment. The basic parameters are (in this application) voltage, current, resistance, power, and frequency.

The discussion of measuring instruments includes test equipment classes designated as multimeters, electronic voltmeters, power measuring devices, and frequency meters.

REVIEW OF METER OPERATION

There must be some source of power available to operate a meter. Some meters are powered by batteries installed in the meter case, others are supplied through an electrical power cord which is plugged into a power receptacle; a vacuum tube voltmeter (VTVM) is an example of the latter type. The power to operate some meters (such as the megger) is produced by manual operation of a handcrank. Each of these three types are described in the following paragraphs.

Most meters are designed to be used for measuring more than one electrical quantity, and are called multimeters. Before discussing any one particular type meter, a brief review of each of the basic meters is presented.

Ammeter

The amplitude of current flow through the basic meter mechanism limits it to measuring a fixed range of only a fraction of an ampere. To overcome this limitation, and to protect the mechanism, a current shunt is used. This device, which is actually a resistance of low value, permits the instrument to serve as a d-c ammeter in the measurement of relatively large direct currents.

The current distribution between meter movement and shunt is inversely proportional to their individual resistances. Thus, the shunt (which has less resistance) carries the majority of the current. Since the meter coil carries only a small portion of the circuit current, it is capable of indicating relatively large values of circuit current. The instrument may be adapted to a variety of current ranges by the use of shunts of different values. Figure 17-1 shows a simplified schematic diagram of an ammeter-section taken from a typical volt-ohm-milliammeter.

Ohmmeter

For any given ohmmeter, midscale deflection is obtained when the current drawn by the meter is one-half the value of the current at full-scale (zero ohms) deflection. This condition exists when the resistance being measured is equal to the total meter circuit resistance. Analysis of the circuit in figure 17-2 shows the full-scale deflection is obtained when the meter probes are shorted together, and that less than full-scale deflection is obtained when the resistance to be measured, R_X, is connected into the circuit. If the meter now reads one-half of its former current, it follows that the total circuit

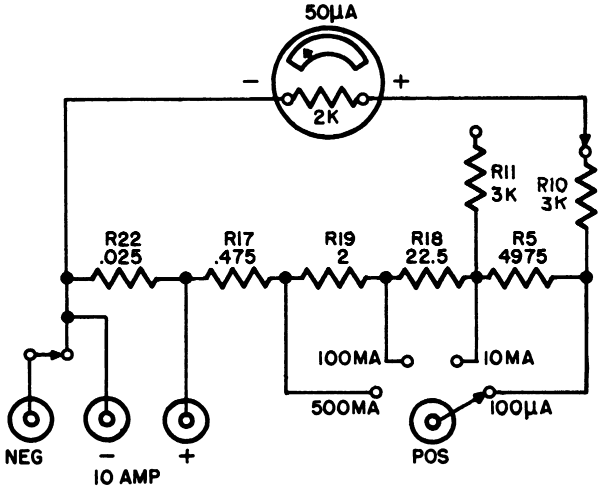


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Figure 17-1.—Simplified schematic diagram of an ammeter.

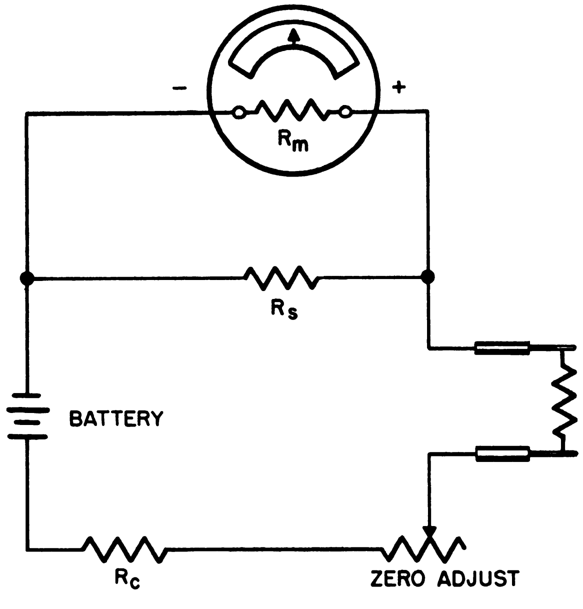

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Figure 17-2.—Series type ohmmeter basic circuit.

resistance has doubled, indicating that R_X is equal to the total meter circuit resistance.

Since the ohms-calibrated scale is nonlinear, the midscale portion represents the most accurate portion of the scale. However, the usable range extends with reasonable accuracy on the high end to ten times the midscale reading, and on the low end to one-tenth of the midscale reading.

To extend the range of an ohmmeter, the proper values of shunt and series resistors and battery voltages are connected into the circuit so that with the test leads shorted the meter will read full scale. Figure 17-3 shows a simplified schematic diagram of an ohmmeter section taken from a typical volt-ohm-milliammeter.

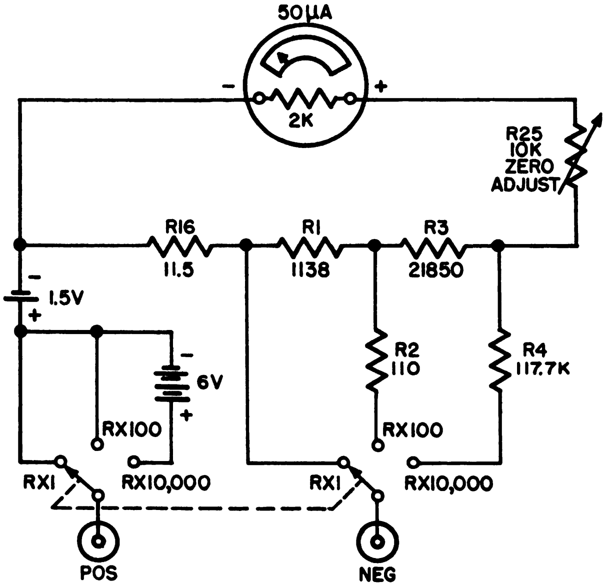

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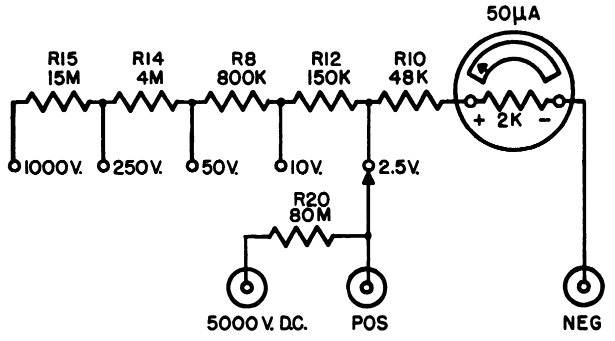
Figure 17-3.—Simplified schematic diagram of an ohmmeter.

Voltmeter

To make the basic meter mechanism suitable for measuring d-c voltages, the voltage multiplying resistor is added. The voltage multiplying resistor is placed in series with the coil (fig. 17-4) and limits the flow of current to a safe value.

Since the value of the resistor is constant for any given application, the flow of current through the coil is proportional to the voltage under measurement. By proper calibration of



AT.91

Figure 17-4.—Simplified schematic diagram of a d-c voltmeter.

the dial, the instrument may be made to indicate voltage although it is actually activated by currents. In practice, the voltage ranges of the instrument are established by the use of different values of multiplying resistors.

NONELECTRONIC METERS

Much of the technician's work requiring the use of a volt-ohm-milliammeter can be accomplished with a portable, battery-operated multimeter. Many shops employ the TS-352, Simpson 260, Simpson 160, or the PSM-4 for field use (troubleshooting in the aircraft, for instance). The technician will, however, often need a more sensitive meter—one that gives more accurate readings and has wider ranges.

Equipment schematics and wiring diagrams often specify that voltages indicated at test points were obtained by using a meter of a certain sensitivity, such as a 20,000-ohms-per-volt meter. A meter of the same sensitivity should be used when repairing that equipment in order to obtain accurate readings.

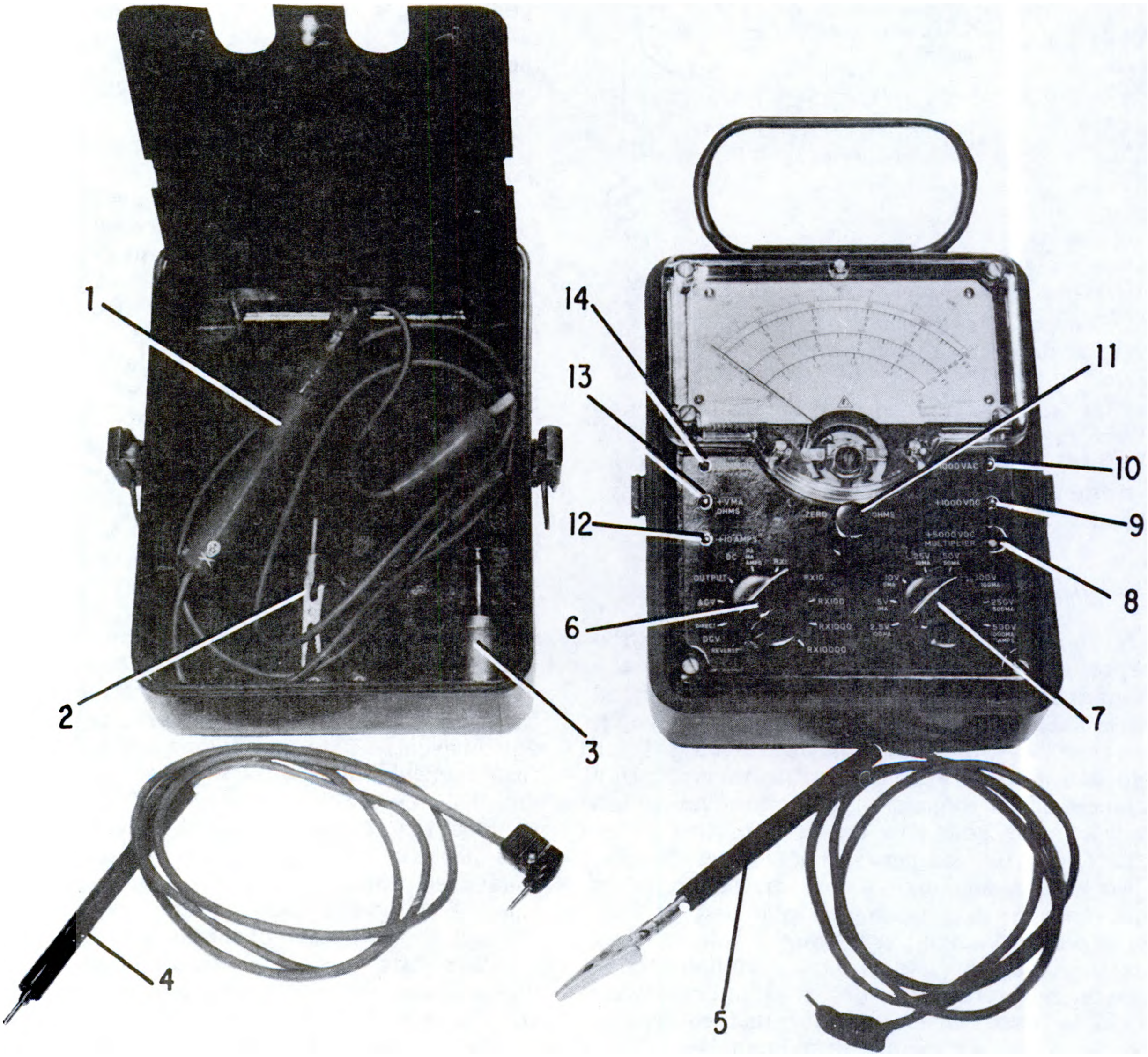
Multimeter AN/PSM-4C

The multimeter AN/PSM-4C (fig. 17-5) is designed to permit the technician to make measurements of voltage, resistance, and current with a completely self-contained portable instrument. It can measure either a-c or d-c voltage, d-c resistance, or direct current in a wide range of values. This capability covers the basic requirements for a portable tester of this type. All leads and accessories are stored in a compartment built into the cover, which remains with the instrument at all times. The cover forms a watertight seal when clamped over the face of the meter. While the instrument is in use, the cover clamps over the back of the meter keeping the accessory compartment convenient to the operator. Batteries used with the meter are: one BA-30 (1.5 volts) and one BA-261/U (22.5 volts).

In the accessory compartment there is a pair of standard test leads (one red and one black) which are used for most applications of the instrument. These leads have elbow probes on one end to connect the lead into the circuit jacks on the instrument. They have probe tips on the other end, which have threaded shoulders to accept the alligator clips which are screwed on. These parts are used to make all measurements, except d-c voltage over 1,000 volts.

For measuring d-c voltages over 1,000 volts, a special high voltage probe is provided, and is used in conjunction with the standard black lead. One end of the lead has a threaded tip which screws on a post in the face of the meter (labeled 5,000 VDC MULTIPLIER). The other end of the lead has a high-voltage multiplier assembly made of red plastic with a clear plastic end and terminates in a crocodile clip at the end of a short piece of flexible wire. The clear plastic end allows the operator to observe the glow of a neon lamp when there is high voltage present. This is a warning to the operator that there is high voltage present at the clip and that he should not touch it. The neon lamp is in series with a 100-megohm resistor within the housing. When a high voltage is being measured, the current passes through the lamp making it glow, through the resistor, and through the armature of the meter.

There are three controls on the face of the meter. One is a 10-position rotary switch in the lower left-hand corner which is used as a function switch. Five of the positions on this switch are used to set up different resistance scales. Two of the positions are for selection of d-c voltage measurement (direct and reverse). The normal position of the switch is in the DIRECT position. If a negative voltage is to be measured, the switch is moved to the REVERSE position. (NOTE: Never switch leads to read a reverse or negative voltage.) One position of the switch is marked ACV; in this position the meter may be used to read a-c voltage. A rectifier in the instrument changes the a-c voltage to an equivalent d-c value which is applied to the meter. One position is marked



AQ.583

1. High voltage probe.
2. Alligator clips.
3. Telephone plug.
4. Standard test lead (red).
5. Standard test lead (black).
6. Function switch.
7. Current and voltage range selector.
8. +5,000 VDC multiplier.
9. +1,000 VDC (red lead).
10. 1,000 VAC (red lead).
11. Zero ohms.
12. + 10 amps (red lead).
13. + Volts/MA/ohms (red lead).
14. Common (black lead).

Figure 17-5.—Multimeter AN/PSM-4C.

OUTPUT; in this position the a-c portion of mixed a-c and d-c voltage may be read. The last position of the switch is used when measuring direct current and is marked DC with three ranges (μA, MA, AMPS) indicated to the right of the letters DC. In the lower right-hand corner is an eight-position switch used to select current and voltage ranges. Near the center of the meter is a control marked ZERO OHMS. This control, which is a continuously variable adjustment, is used to zero the meter thus compensating for battery aging in the ohmmeter circuits. This control is adjusted until the meter indicates full-scale deflection (indicating zero ohms) when the function switch is set at one of the resistance range positions and the meter probes are shorted together. To prevent erroneous readings when switching to a different position, a check of the meter zero indication is always necessary.

The multimeter AN/PSM-4C is designed to make the following electrical measurements:

1. Measure direct current up to 10 amperes.
2. Measure resistances up to 300 megohms.
3. Measure d-c voltages up to 5,000 volts.
4. Measure a-c voltages up to 1,000 volts.
5. Measure output voltages up to 500 volts.

Input impedance for measuring d-c voltages is 20,000 ohms per volt and is accurate to within 3 percent of full-scale (4 percent for the 5,000 VDC scale). When measuring a-c voltages, the input impedance is 1,000 ohms per volt and is accurate to within 5 percent of full scale.

Under normal conditions, no routine service inspection is necessary beyond visual examination at established inspection periods. If the instrument is to be stored for periods of 6 months or longer, the batteries must be removed to prevent corrosion. The periodic inspection should include removal of the battery case cover to facilitate inspection of battery connections. If the instrument is used under extreme temperature conditions, a visual inspection of all parts should be made at least once a month. No periodic maintenance is required except for inspection, test, and replacement of batteries.

Milliohmmeter AN/USM-21A

The AN/USM-21A low-range ohmmeter can measure resistances in the range of 10 milliohms or less. Most ohmmeters read zero at such a low value. Several troubleshooting problems can be solved easily with such an instrument. One of the most common and troublesome is to find the exact location of a short circuit in a power distribution circuit involving many parallel paths.

In using the milliohmmeter, several problems are encountered. These problems include stray circuit resistances such as contact resistance, test lead resistance, and switching resistance. In using the conventional low-range ohmmeters, the primary limitation is in the contact resistance at the test probes.

The AN/USM-21A was designed principally to overcome the contact resistance problem. A measured current is passed through the test circuit by means of a heavy set of clip leads. Using an auxiliary set of test leads which carry very little current, the resulting voltage drop across the test circuit is measured by a sensitive millivoltmeter which senses this voltage.

Megger

A megger is an instrument that applies a high voltage to the component under test and measures the current leakage of the insulation. Thus a capacitor or insulated cable can be checked for leakage under much higher voltages than an ohmmeter is capable of supplying. It consists of a hand-driven, d-c generator and an indicating meter. The name megger is derived from the fact that it measures resistances of many megohms.

There are various resistance ratings of meggers with full-scale values as low as 5 megohms, and as high as 10,000 megohms. Figure 17-6 shows the scale of a 100-megohm, 500-volt megger. Notice that the upper limit is infinity and that the scale is crowded at the upper end. The first scale marking below infinity represents the highest value for which the instrument can be accurately used. Thus, if the pointer goes to infinity while making a test, it means only that the resistance is higher than the range of the set.

There are also various voltage ratings of meggers (100, 500, 750, 1,000, 2,500, etc.). The most common type is the one with a 500-volt rating. This voltage rating refers to the maximum output voltage of the megger. The output voltage is dependent upon the speed of turning of the crank and armature. When the megger's armature rotation reaches a predetermined speed, a slip clutch will maintain the armature at a constant speed. The voltage

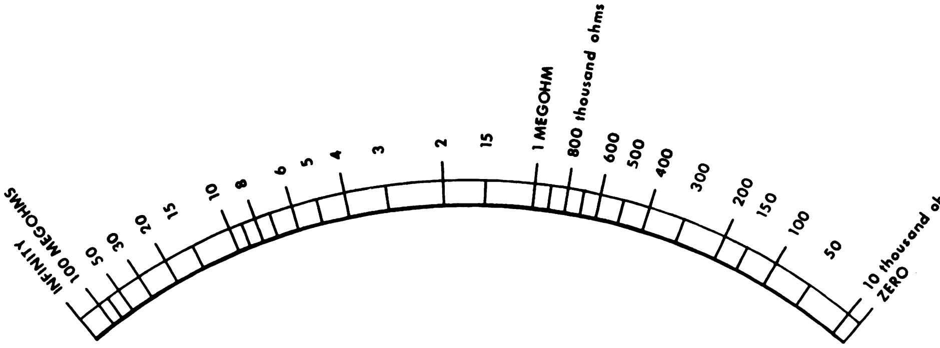


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Figure 17-6.—Scale of 100-megohm, 500-volt megger.

rating is important, for the application of too high a voltage to even a good component will cause a breakdown. In other words, do not use a 500-volt megger to test a capacitor rated at 100 volts.

Meggers are used to test the insulation resistance of conductors in which shorting or breaking down under high voltage is suspected. In some situations, meggers are used in the prevention of unnecessary breakdowns by maintaining a record of insulation resistance of power and high-voltage cables, motor and generator windings, and transmission lines. These records will reflect fluctuations in resistance and aid in determining when the components should be replaced to prevent a breakdown.

Meggers are used for testing capacitors whose peak voltages are not below the output of the megger. They are also used for testing for high-resistance grounds or leakage on such devices as antennas and insulators.

Precautions to be followed in the use of the megger are as follows:

1. When making a megger test, the equipment must not be energized. It must be disconnected entirely from the system before it is tested.

2. Observe all rules for safety in preparing equipment for test and in testing, especially when testing installed high-voltage apparatus.

3. Use well-insulated test leads, especially when using high-range meggers. After the leads are connected to the instrument and before connecting them to the component to be tested, operate the megger and make sure there is no leak between the leads. The reading should be infinity. Make certain the leads are not disconnected or broken by touching the test ends of the leads together while turning the crank slowly. The reading should be approximately zero.

4. When using high-range meggers, take proper precautions against electric shock. There is sufficient amount of capacitance in most electrical equipment to "store up" sufficient energy from the megger generator to give a very disagreeable and even dangerous electric shock. Owing to a high protective resistance in the megger, its open circuit voltage is not as dangerous, but care should be exercised.

5. Equipment having considerable capacitance should be discharged before and after making megger tests in order to avoid the danger of receiving a shock. This can be accomplished by grounding or short circuiting the terminals of the equipment under test.

ELECTRONIC METERS

Electronic meters are used primarily for the same purposes as are the nonelectronic meters. Some characteristics of their operation, however, give them definite advantages. In the electronic multimeter, the current and resistance measuring circuits function in a manner identical to the corresponding nonelectronic measuring instruments. The measurement of voltage, however, involves the use of an amplifier which in turn requires that the meter be calibrated prior to use.

Proper calibration and use of the instruments vary slightly according to model. Details are included in the Operation Instruction Manual for each model.

The ordinary voltmeter has several disadvantages that make it practically useless for measuring voltages in high-impedance circuits. For example, suppose that the plate voltage of a pentode amplifier is to be measured. (See fig. 17-7.) When the meter is connected between the plate and cathode of the electron tube, the meter resistance R_m, is placed in parallel with the effective plate resistance R_{eff}, thereby lowering the effective plate resistance. The effective plate resistance is in series with the plate load resistor, R_L, and this series circuit appears across the supply voltage, E_{bb}, as a voltage divider. Since the overall resistance is lowered, it follows that current through R_L will also increase, the voltage drop across R_L will also increase, and the voltage drop across R_{eff} will decrease. The result is an incorrect indication of plate voltage, and is called loading effect.

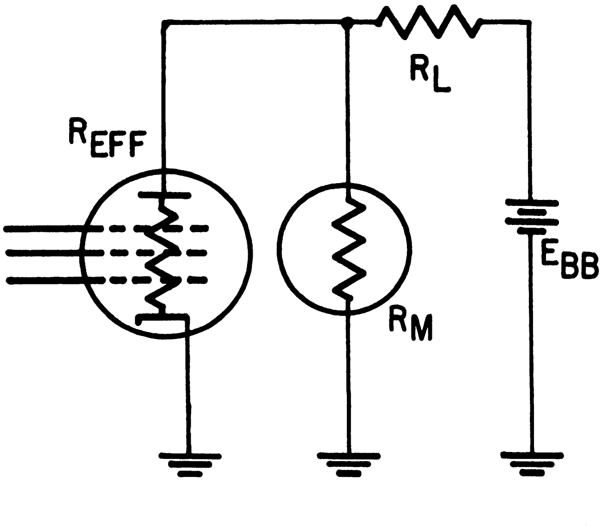

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Figure 17-7.—Loading effect created by meter resistance.

Calculation of Loading Effects

Before the voltmeter is connected, the plate current is determined by the effective resistance of the plate circuit, the plate load resistor, and the plate voltage. If the tube has an effective resistance of 100,000 ohms, a plate load resistance of 100,000 ohms, and the plate power supply is constant at 200 volts, then the plate current is

$$\frac{200 \text{ v}}{200{,}000\ \Omega}$$

or 0.001 ampere. The plate voltage (plate to cathode) is 0.001 x 100,000, or 100 volts.

Assume that the voltmeter used to measure the plate voltage of the tube has a sensitivity of 1,000 ohms per volt and that the selected meter range is from 0 to 250 volts. The meter will then have a resistance of 250,000 ohms. This resistance in parallel with the tube resistance of 100,000 ohms produces an effective resistance of 71,400 ohms in series with the plate load resistor. The total resistance across the plate voltage supply is therefore 171,400 ohms instead of the 200,000 ohms before the meter was applied, and the current through the plate load resistor is

$$\frac{200 \text{ v}}{171{,}400\ \Omega}$$

or 0.00117 ampere. Across the plate load resistor the voltage drop is 0.00117 x 100,000, or 117 volts, and the plate-to-cathode voltage on the tube is 200 - 117, or 83 volts when the meter is connected, thus causing an error of 17 volts. The lower the sensitivity of the meter, the greater the error will be; in this example, the error of 17 volts when the reading should be 100 volts is a 17-percent error.

A meter having a sensitivity of 20,000 ohms per volt and a 250-volt maximum scale reading would introduce an error of about 1 percent. However, in circuits where very high impedances are encountered, such as in grid circuits of electron tubes, even a meter of 20,000 ohms per volt sensitivity would impose too much of a load on the circuit.

VTVM Advantages

Another limitation of the alternating current, rectifier type voltmeter is the shunting effect at high frequencies of the relatively large capacitance of the meter's rectifier. This shunting effect may be eliminated by replacing the usual metallic oxide rectifier with a diode electron tube; the output of the diode is applied to the grid of an amplifier in which the plate circuit contains the d-c meter. Such a device is called an electron tube voltmeter or a vacuum tube voltmeter, usually abbreviated VTVM. Voltages at frequencies up to 500 megahertz, and sometimes even higher, can be measured accurately with this type of meter. The frequency limitation is determined by the model of VTVM.

The input impedance of a VTVM is large, and therefore the current drawn from the circuit whose voltage is being measured is small and in most cases negligible. The main reason for using a vacuum tube voltmeter is to overcome the loading effect by taking advantage of the VTVM's extremely high input impedance. A VTVM that is used extensively for electronics maintenance is contained in the TS-505 multimeter.

Vacuum Tube Voltmeter TS-505

Figure 17-8 shows a front panel view of the TS-505. The VTVM measures d-c voltages from 0.05 volt to 1,000 volts (in 9 ranges), and a-c voltages from 0.05 volt to 250 volts rms (in 7 ranges), at frequencies from 30 Hz to 1 MHz. With the RF adapter that is used with the d-c voltage measurement circuit, RF voltages may be measured from 0.05 volt to 40 volts rms at frequencies from 500 kHz to 500 MHz. D-C resistances from 1 ohm to 1,000 megohms may be measured.

The accuracy of this meter is good, being 5 percent for d-c voltages and 6 percent for a-c and RF voltages. The meter movement requires 1 ma for full-scale deflection.

The input impedance to the meter is 6 megohms at audiofrequencies, 40 megohms on the 1,000-volt d-c range, and 20 megohms on all other ranges.

The power requirement is 98 to 132 volts, single phase, 50 to 1,000 Hz, at about 21 volt-amperes.

The removable cover of the TS-505 contains accessories such as alligator clips, an RF adapter, and miniature probe tips. The miniature tips slip over the regular tips when working in confined areas.

OPERATING CONTROLS.—The controls that you will use when operating the meter (fig. 17-8) are as follows:

1. FUNCTION switch: Selects the type of multimeter operation desired and turns the multimeter on or off.
2. RANGE switch: Selects various voltage or resistance measurement ranges.
3. ZERO ADJ. control: Controls pointer of indicating meter. Used to set the meter pointer at zero on the +DC, -DC, AC, or OHM scale, or at midscale on the ±DC scale.
4. OHMS ADJ. control: Controls pointer of indicating meter. Used to set the meter pointer at ∞ on the OHMS scale when the FUNCTION switch is set on OHMS position.
5. Meter: Indicates the value of voltage or resistance measured.
6. AC LINE cord: Connect multimeter to a-c power source.
7. COMMON probe: Connects the ground, or common circuit of the multimeter, to the equipment under test.
8. DC probe: Connects equipment under test to the d-c measuring circuit of the multimeter.
9. OHMS probe: Connects equipment under test to the ohmmeter circuit of the multimeter.
10. AC probe: Connects equipment under test to the a-c measuring circuits of the multimeter.
11. Pilot light indicator: Lights when power is applied to the multimeter.

TECHNIQUES FOR USE.—The operation of this meter is virtually self-explanatory. By studying the controls and their respective markings, you should be able to determine the steps to follow when making a particular measurement. Do not attempt to use this instrument unless you have studied the technical manual which sets forth the operating procedures, or unless you have been instructed in its proper usage, under the direction of your shop supervisor.

Two peculiarities of this meter are:

1. In order for it to indicate accurate readings it must warm up. This usually takes about 10 minutes. During this period the meter pointer may drift rapidly; this is normal.
2. Voltage measurements cannot be read directly on the meter scale when the function switch is set at the ±DC position.

The purpose of the ±DC position (zero center scale) is to determine the polarity of an unknown d-c voltage or to indicate a zero d-c voltage input to the multimeter.

CAUTION: The maximum d-c voltage which may be applied to the multimeter when the function switch is set at the ±DC position is one-half of the voltage indicated by the panel marking opposite the range switch setting.

The major difference between any VTVM and a conventional multimeter is that the VTVM utilizes a vacuum tube in its input. For a detailed explanation of the circuitry of the TS-505 VTVM consult the manufacturer's manual or the Operation and Service Instruction Manual.

Phase Angle Voltmeters

The overall accuracy of many electronic equipments is determined by measuring phase angles in computing transformers, computing amplifiers, and resolver systems. In the past, one of the most common methods used for measuring phase shift or phase angles between signals was observing patterns on an oscilloscope. With this method, it was hard to determine small angles, and difficult to translate various points into angles and sines of angles. The most limiting factor in using oscilloscope patterns developed when one of the signals contained harmonic distortion or noise.

In any complex waveform containing a fundamental frequency and harmonics, measuring phase shifts presents problems. In most applications, interest lies in the phase relationship of the fundamental frequency, regardless of the phase relationship of any harmonics which may be present. One of the requirements of a phase measuring device is to measure the phase difference between two discrete frequencies, regardless of the phase and amplitude of other components of the waveform.

The basic block diagram of a phase angle voltmeter is shown in figure 17-9. There are two inputs—the signal and the reference. Both channels contain filters which pass only the fundamental frequency. All other frequencies are highly attenuated. Each channel has a variable amplitude control and amplifiers to increase the variety of signals that can be checked.

A calibrated phase shifter is inserted into one channel; that channel signal can be phase shifted to correspond to the other channel. This is detected in the phase detector and observed on the meter.

The calibrated phase shifter is made up of a switch (whose position corresponds to the 0°, 90°, 180°, and 270° phase shift) and a potentiometer (whose dial is calibrated from 0° to 90°). The total phase shift is made up of the sum of the two readings.

The phase detector is a balanced diode bridge type demodulator. Its output is proportional to the signal frequency amplitude times the cosine of the angle of phase difference between the signal input and the reference input.

If the reference input is phase shifted until it is in phase or 180° out of phase with the signal input, the output from the phase detector is proportional to the signal input amplitude (the cosine of the angle is unity). If the reference input is phase shifted until it is 90° or 270° from the signal input, the phase detector output is zero (the cosine of the angle is zero).

The point at which the two signals are in phase or 180° out of phase is the point of maximum deflection on the meter. The difference between the in phase and the 180° out of phase points is in the direction in which the needle swings—not the distance it swings. As the point of maximum deflection is approached, the rate of change of the meter reading decreases because the cosine has a small rate of change near 0°. This makes it difficult to read the exact point of maximum deflection.

Because the cosine has a maximum rate of change as it approaches 90° (and thus gives a better indication on the meter), most commercial voltmeters are set to determine the point at which the signals are 90° out of phase—"quadrature." When the voltmeter is set for this point, there must be some way of converting the phase shifter reading so that it shows the correct amount of phase shift rather than 90° more or less than the actual amount. Some confusion exists in this area because different manufacturers have different methods of determining the signal quadrant. Manufacturers also differ on whether the final reading is a leading or a lagging phase shift. This means the technician must be familiar with as many types of phase angle voltmeters as the Navy has in the field. He cannot assume that the method he uses to determine phase angle on one type of meter can be used on another; nor can he assume that, because one meter gives him a leading angle between signal and reference waveforms, another manufacturer's meter also gives leading phase shift.

Differential Voltmeter

The differential voltmeter is a reliable precision item of test equipment. Its general function is to compare an unknown voltage with an internal reference voltage, and to indicate

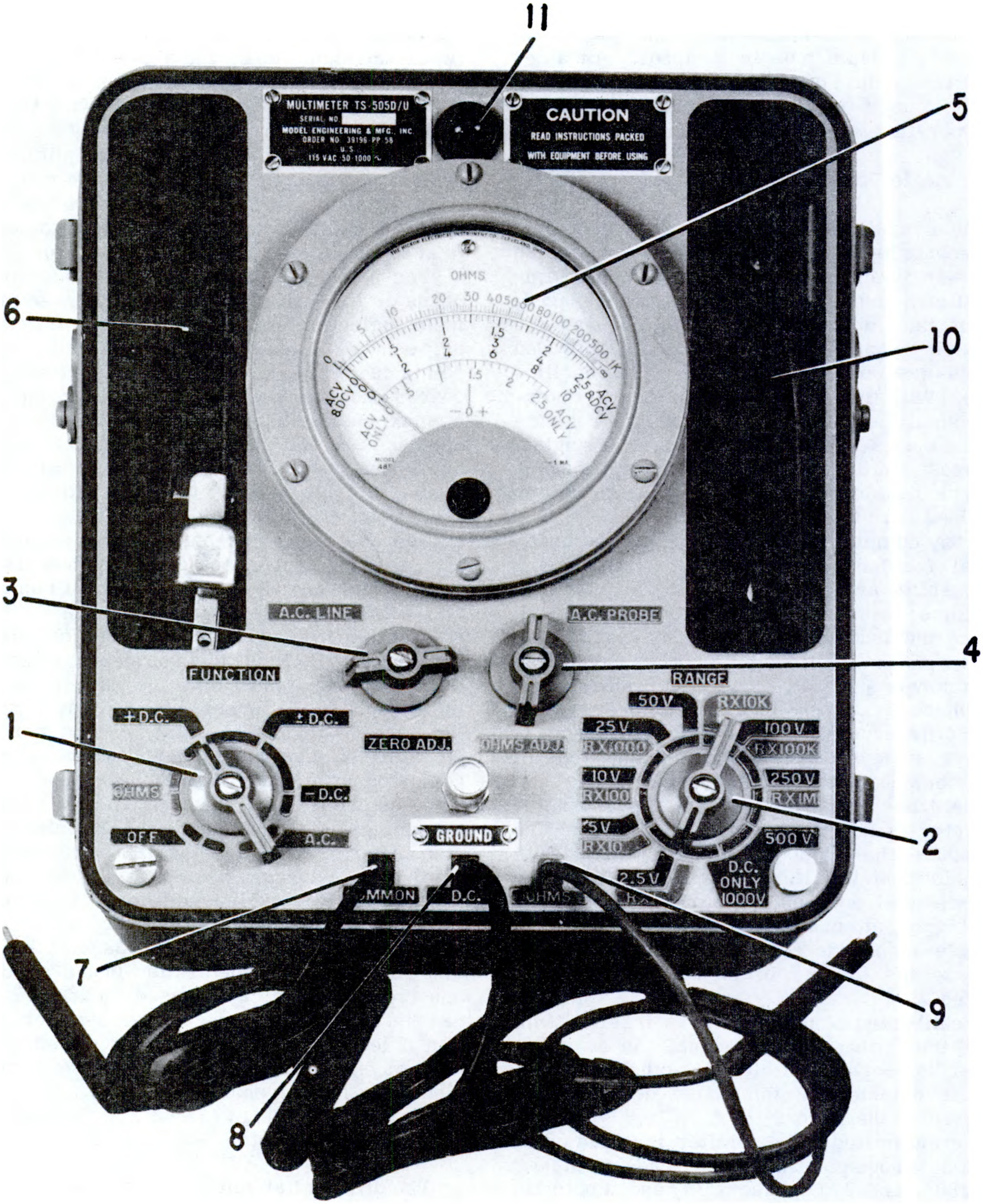

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Figure 17-8.—TS-505 multimeter, front panel.

Nomenclature for figure 17-8.

1. Function switch.
2. Range switch.
3. Zero adjust.
4. Ohms adjust.
5. Meter.
6. A-C line cord (power cord).
7. Common probe (black).
8. D-C probe (black, special tip).
9. Ohms probe (green).
10. A-C probe (red).
11. Indicator lamp (glows red with power on).

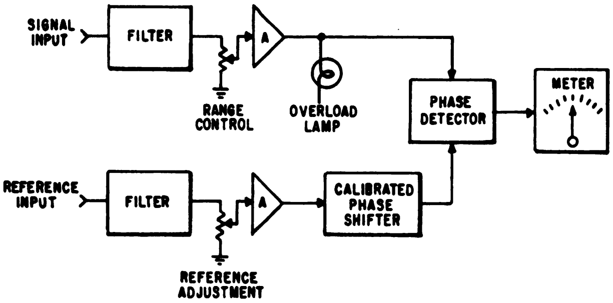

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Figure 17-9.—Phase angle voltmeter, block diagram.

the difference in their values. The differential voltmeter in most common use in Navy applications is the 803D/AD (fig. 17-10), manufactured by the John Fluke Co. The remaining portion of this discussion is based on that instrument.

The 803D/AD is usable as an electronic voltmeter, as a precision potentiometer, and as a megohmmeter. It can also be used to measure the excursions of a voltage about a reference value. Ease of operation, inherent protection from any accidental overload, and high reliability of readings are additional advantages of the instrument. It is accurate enough for precision work in calibration laboratories, yet rugged enough for general shop use.

The heart of the unit is a precision 500-volt d-c reference power supply. This 500 volts can be precisely divided into increments as small as 10 microvolts by means of 5 voltage dials. Unknown a-c or d-c voltages are matched against the precise internal voltage until no deflection occurs on the panel meter. The unknown voltage is then simply read from the voltage dials. In the highest null sensitivity range, a potential difference between unknown and reference voltage as small as 0.01 volt causes full scale meter deflection.

At null, the differential voltmeter presents an "infinite" input impedance to the voltage under measurement, almost completely eliminating circuit loading.

A functional block diagram of the differential voltmeter is shown in figure 17-11. The principal circuit divisions are as follows:

1. A 500-volt d-c reference power supply.
2. Precision voltage divider network.
3. VTVM.
4. Chopper-amplifier.
5. Converter and converter power supply.

The system circuitry is designed with two separate common returns. One of these, the return for the converter power supply and reference power supply, provides a safety factor for personnel and a capability for measuring a potential difference between two voltages. The other, which is the common return of the VTVM power supply, is connected to the known reference voltage output from the precision voltage divider network. This arrangement provides a constant d-c voltage of +108 volts across the differential amplifier regardless of the d-c potential applied to the grid.

D-C REFERENCE POWER SUPPLY.—A full wave rectifier with its associated filter network supplies a d-c voltage of approximately 1,000 volts to a conventional electron controlled voltage regulator. The regulated output is maintained at 500 volts ± 0.01 percent.

In the 500 V DC position, the RANGE switch (S2E) passes this 500 volts directly to the precision voltage divider. In the 50 V DC, 5 V DC, and 0.5 V DC positions, range resistors S2F divide the reference voltage to 50, 5, and 0.5 volts d.c., respectively. In all a-c positions of the RANGE switch, only 5 volts of the reference supply is used, due to the fact that the maximum output of the a-c to d-c converter is 5 volts

PRECISION VOLTAGE DIVIDER.—Each of the four precision voltages available from the reference supply must be made adjustable through a precision divider network so that

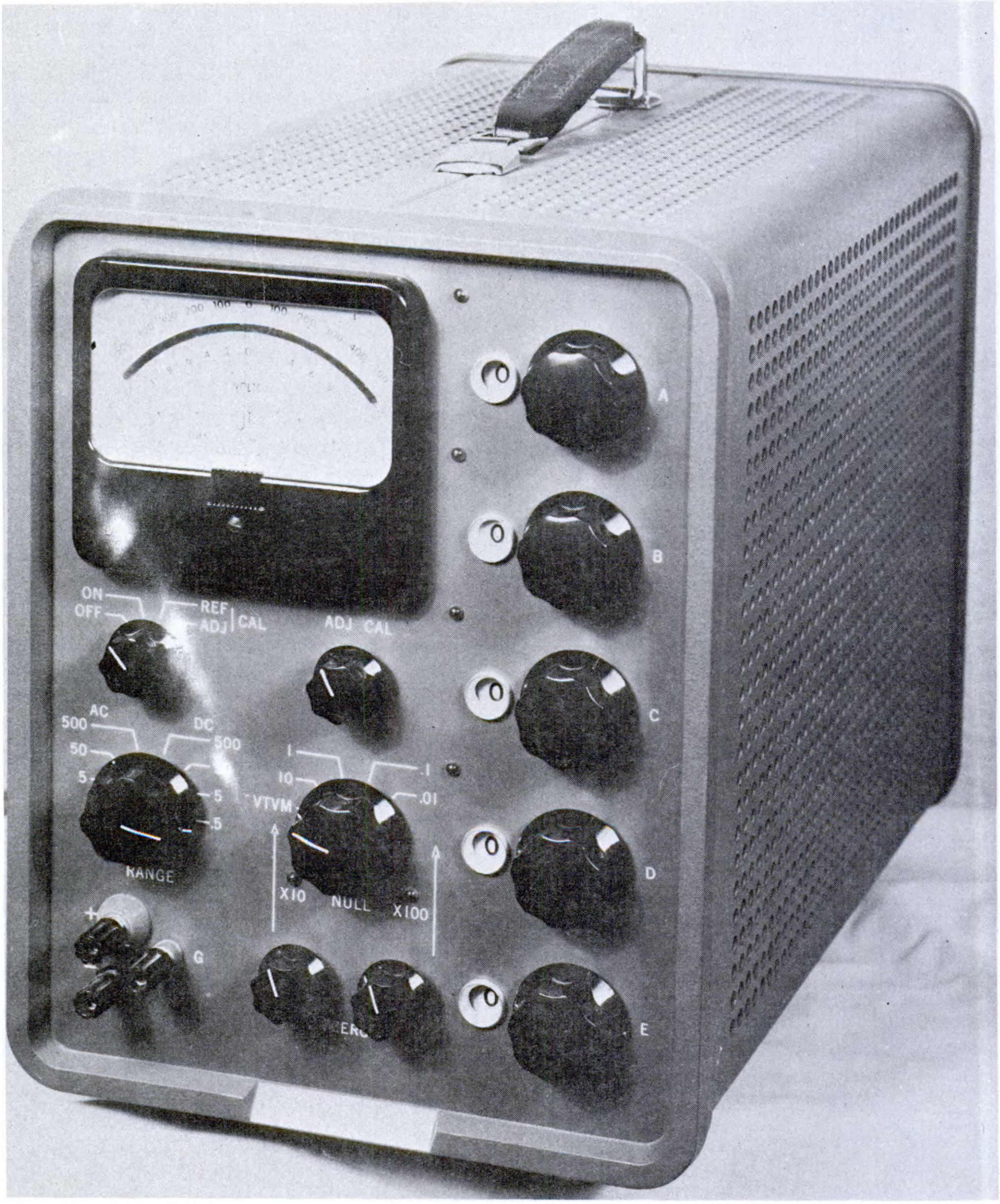

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Figure 17-10.—Differential voltmeter, Model 803D/AD.

unknown voltages may be nulled or matched exactly. The five decade resistor strings (fig. 17-12) accomplish this function.

Note that each string, with the exception of the first, parallels two resistors of the string that precedes it. Between the two wipers of S4, there is a total resistance of 40K and a total voltage of 100 volts d.c. with the RANGE switch in the 500 V DC position. Across the wipers of S5, S6, and S7, there are 10, 1, and 0.1 volts d.c., respectively. Switch S8 selects increments of 0.01-volt d.c. from the last decade. These voltages are reduced by a factor of 10 for each successively lower voltage range.

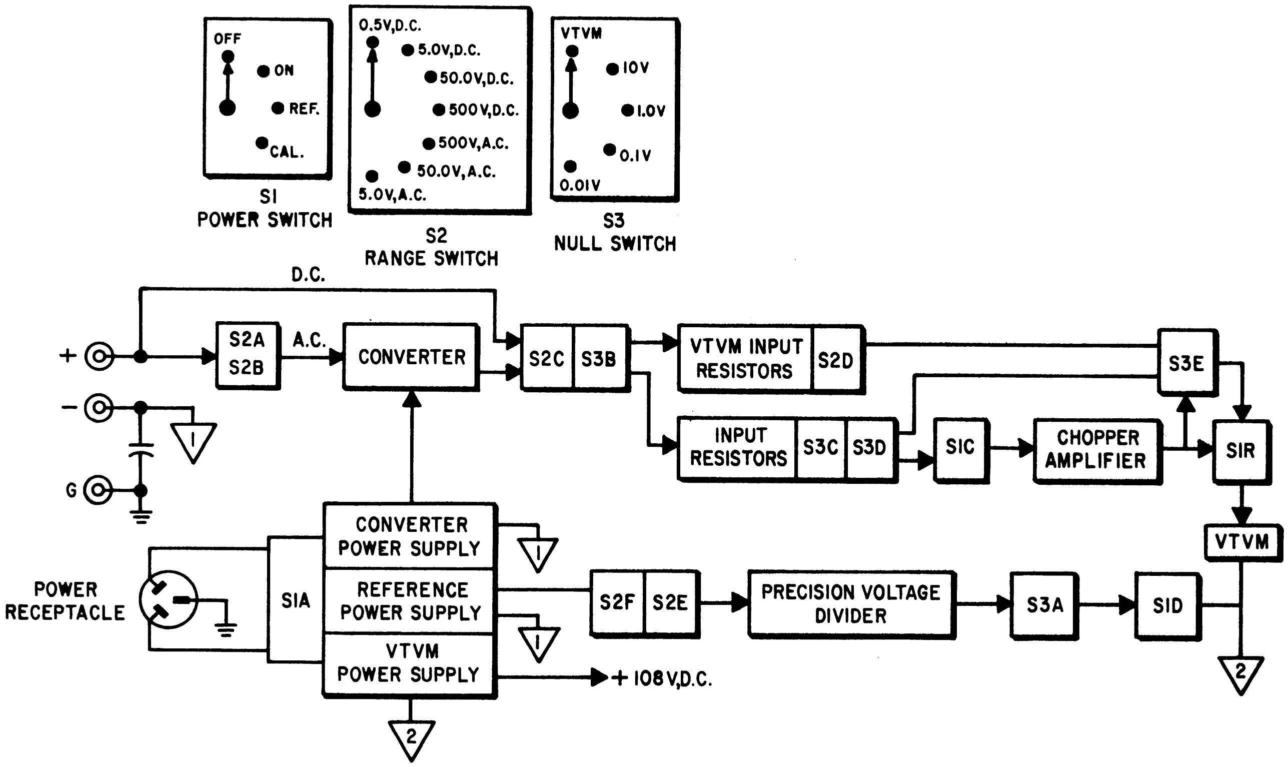

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Figure 17-11.—Differential voltmeter, functional block diagram.

All resistors of each decade are matched and all decades are matched for each instrument, providing an overall divider accuracy of 0.005 percent.

With the NULL switch in any null range, the output of the precision voltage divider appears at the grid of one-half of the VTVM differential amplifier. A one two-hundredths ampere (5 milliampere) fuse protects this output.

VACUUM TUBE VOLTMETER.—When operating in the differential mode, output voltage from the precision voltage divider appears on the grid of V4B, one-half of the differential amplifier. (See fig. 17-13.) The unknown voltage appears on the grid of V4A, the other half of the differential amplifier. Any difference between these potentials is indicated by the meter coupled between the cathodes of V4A and V4B. When the output voltage exactly matches the unknown, the meter reads zero and no current is drawn from the source being measured, because the same potential exists on both sides of the input resistances.

When used as a conventional VTVM, the grid of V4B is connected to the 0-volt bus, or negative binding post. With the range switch in the 0.5 V DC position, the unknown voltage appears directly on the grid of V4A and the meter indicates the approximate value of the unknown. Input divider resistors maintain the 0 to 0.5 grid voltage range for all instrument voltage ranges. The input resistance of the instrument in the VTVM position is 10 megohms.

CONVERTER.—All a-c measurements are made by first converting the a-c input to a d-c voltage. The converter provides a maximum d-c output of 5 volts for a maximum a-c input of 5 volts rms. In the 5 V AC position, range switch sections of S2A and S2B couple the converter amplifier input directly to the binding post. In the 50 V AC and 500 V AC positions, input attenuators reduce the unknown a.c. to provide a maximum of 5 volts a-c input to the first converter amplifier.

The overall frequency response of the converter is essentially flat from 30 Hz to 10 kHz.

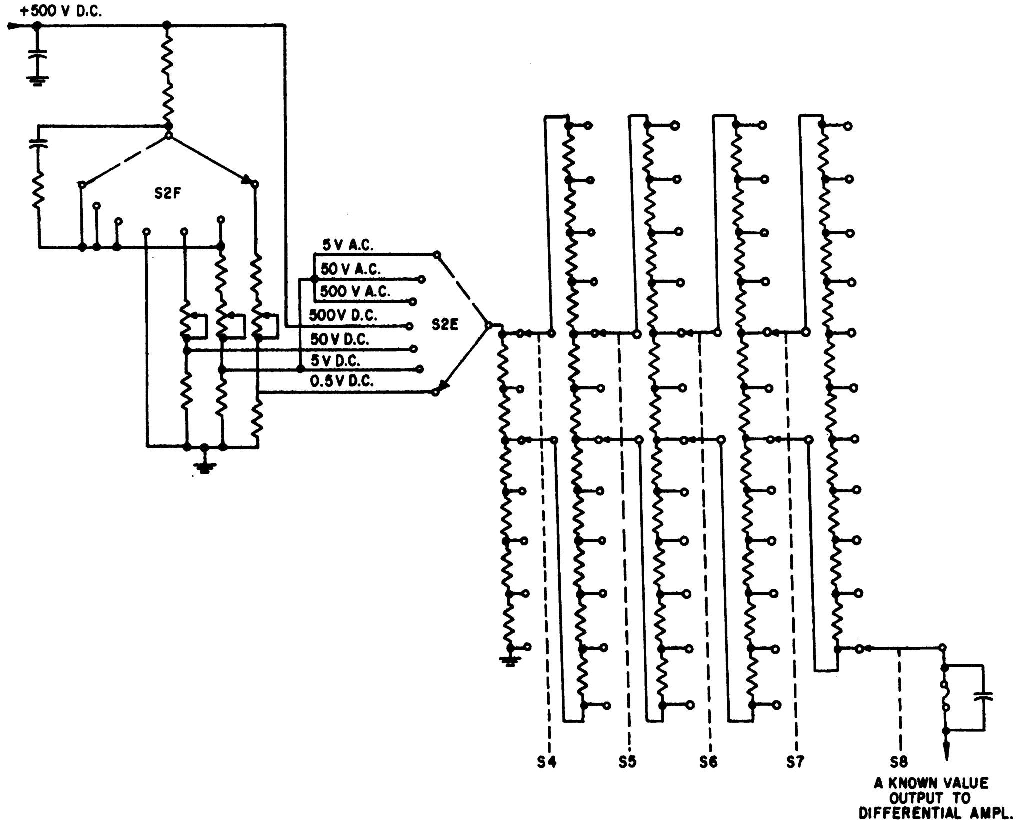

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Figure 17-12.—Precision voltage divider.

MODEL 5015 SPA DIGITAL VOLTMETER

The Model 5015 SPA Digital Voltmeter provides users a highly accurate, easily maintained instrument which also possesses a high order of reliability. The meter uses a relay-operated digital feedback voltage divider, energized by a 10-volt Zener reference voltage, to create a precision feedback voltage equal to the unknown input.

Continuous comparison is made between the feedback voltage and the unknown input; any error voltage is amplified and used to reposition the feedback voltage divider.

An automatically operated attenuator provides operation on the 100-volt and 1,000-volt ranges by dividing the inputs by 10 and 100, respectively. Matched and aged Zener diodes eliminate the need for a temperature-controlled oven.

The Model 5015 SPA digital voltmeter (fig. 17-14) has seven front panel controls. Their functions are described in the following paragraphs:

1. The SENSITIVITY control is a potentiometer that is provided to decrease sensitivity for noisy signals.
2. The FILTER switch is provided to engage or remove the filter application.
3. The power switch has three positions: (1) OFF—the digital voltmeter is deenergized and both power leads are isolated from the power source; however, connection is maintained between the outer case and the a-c power line ground. (2) STBY—this position is provided to allow a warm up selection without any activation of internal components even with an input signal applied. (See paragraph on PUSH TO READ for exception.) (3) ON—in this position the digital voltmeter is ready to provide measurement readings of input signals.

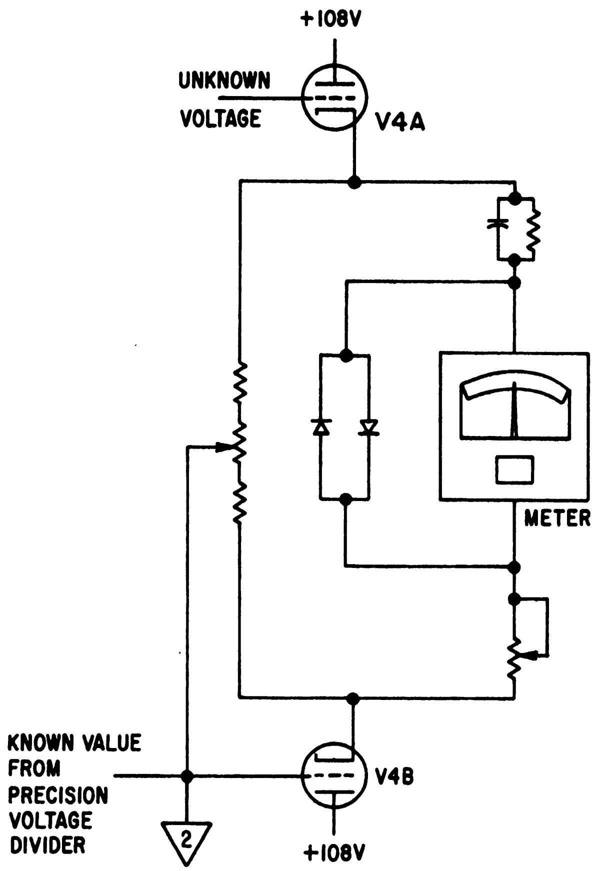

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Figure 17-13.—Differential amplifier.

4. With an input signal applied and the power switch in the STBY position, depressing the PUSH TO READ switch permits the operator to take a single reading.

5. The AC OFFSET control is a screwdriver adjust potentiometer provided to "zero" the readout in the AC mode prior to taking a-c readings.

6. The function switch is provided to permit the selection of either the RATIO, DC volts, or AC volts modes of operation.

7. The range switch has four positions: (1) The 10, 100, and 1,000 positions are used to fix the maximum voltage which will be read. (2) The AUTO position causes the digital voltmeter to select automatically the appropriate range for the input applied.

FREQUENCY MEASUREMENT

Frequency measurements are often an essential part of preventive and corrective maintenance for electronic equipment. Rotation frequencies of some mechanical devices must be determined. The output frequency of electric power generators is checked when the engine is started and during preventive maintenance routines. Equipment which operates in the audiofrequency range must be adjusted to operate at the correct frequencies. Radio transmitters must be accurately tuned to the assigned frequencies to provide reliable communications and avoid interfering with radio circuits operating on other frequencies. Radar sets must be properly tuned to obtain satisfactory performance.

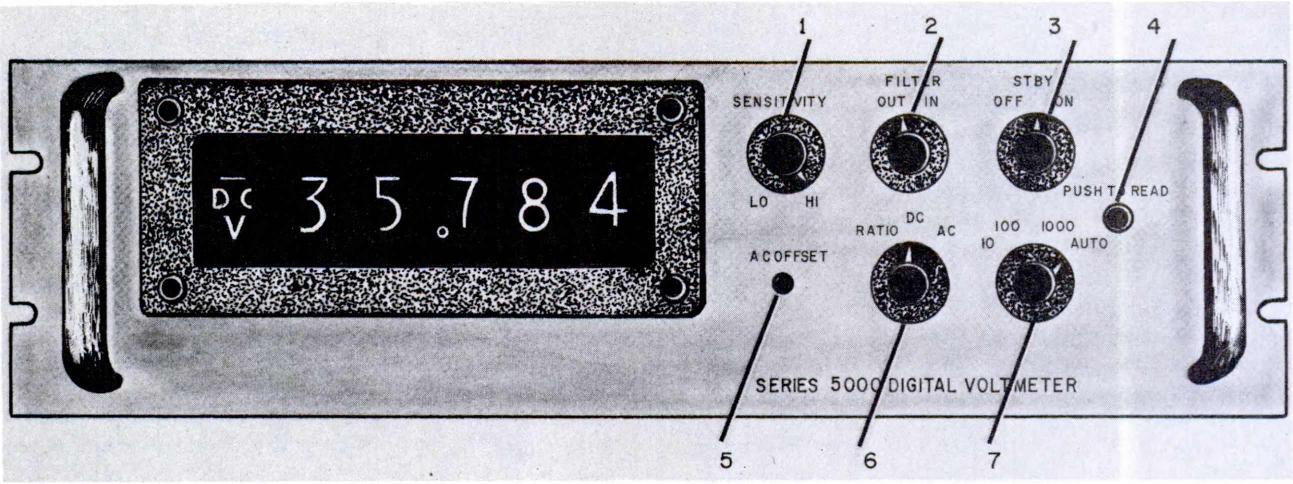
The rotation frequency of rotating machinery such as radar antennas, servomotors, and other types of electric motors can be measured by the use of a stroboscope. Stroboscopic methods compare the rate of one mechanical rotation or vibration with another or with the frequency of a fluctuating source of illumination. Tachometers can be used to measure the rotation frequency of armatures in electric motors, dynamotors, and engine-driven generators.

The electrical output frequency of a-c power generators can be measured directly by vibrating reed, tuned circuit, or crossed-coil iron-vane type meters. The vibrating reed device is the simplest type of frequency meter, and has the advantage of being rugged enough to be mounted on generator control panels. It is also used to check the line voltage in the shop to insure that the proper frequency is supplied to the equipment and/or test sets.

Frequency Meters

"Frequency meter" is a term generally applied to denote an item of test equipment which is used to indicate the frequency of an external signal. Although some models of frequency meters generate signals having a basic frequency, they should not be confused with that class of test equipment known as signal generators. (Signal generators are discussed later in this chapter.) The signal generator develops a frequency used to operate an external circuit; the frequency meter measures the frequency of a signal developed in an external circuit.

As mentioned previously, some frequency meters generate a signal frequency; others do



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1. SENSITIVITY control.
2. FILTER switch.
3. Power switch.
4. PUSH to READ switch.
5. AC OFFSET control.
6. Function switch.
7. Range switch.

Figure 17-14.—Model 5015 SPA digital voltmeter front panel controls.

not. The group in which no frequency is generated internally is properly called a "wavemeter." Wavemeters are of two basic types—reaction and absorption. Those frequency meters which do generate an internal frequency may use either electronic or mechanical oscillation as the frequency generator.

Measurement Methods

Frequency measurements in the audiofrequency range can be made by the comparison method or by a direct-reading frequency meter. Frequency comparisons can be made by the use of a calibrated audiofrequency signal generator in conjunction with either an oscilloscope or a modulator and a zero-beat indicator device. Direct-reading frequency measurements can be made by instruments using series frequency-selective electrical networks, bridge test sets having null indicators, or counting type frequency meters.

Since the wavemeter is relatively insensitive, it is very useful in determining the fundamental frequency in a circuit generating multiple harmonics. Calibration of test equipment which measures signals in this frequency range can be checked by comparison with standard frequency signals broadcast by the National Bureau of Standards.

The signal frequencies of radar equipment which operate in the UHF and SHF ranges can be measured by resonant cavity type wavemeters, resonant coaxial line type wavemeters, or Lecher-wire devices. When properly calibrated, resonant cavity and resonant coaxial line wavemeters are more accurate and have better stability than wavemeters used for measurements in the low frequency to VHF range. These frequency-measuring instruments are often furnished as part of communication and electronic equipment, but are also available as general purpose test sets.

Heterodyne Type Meters

Heterodyne type frequency meters are available in several varieties. Although they all function in the same general manner, some differences exist in the manner of accomplishing their purpose.

Test instruments of this class generate a signal within the test set. This signal is mixed with a signal from the equipment under test to obtain a beat frequency. The frequency of one signal is then changed to obtain a zero beat.

(The beat frequency is the difference frequency which results from heterodyning two signals. A zero beat is obtained when heterodyning two signals of the same frequency.) The frequency of the unit under test may be determined by reading the frequency indicator of the test set.

A heterodyne type frequency meter usually consists of a heterodyne oscillator, an RF harmonic amplifier, a crystal-controlled oscillator, a mixer or detector, a modulator, an AF output amplifier, and a means for indicating frequency. (See fig. 17-15.) Most models are furnished with a set of calibration charts giving the dial readings for the frequencies listed, together with a table of the crystal harmonics; thus a complete and accurate frequency coverage over the designated range is provided. Some models indicate the frequency directly on dials.

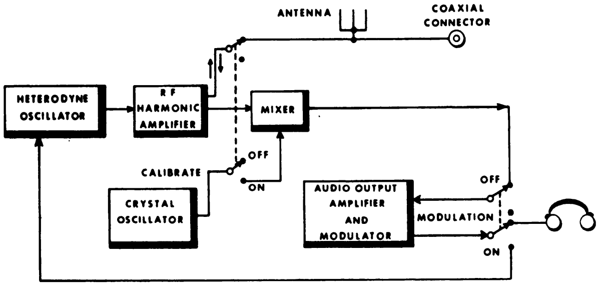

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Figure 17-15.—Crystal-calibrated heterodyne frequency meter, block diagram.

The crystal-controlled oscillator operates at a fixed frequency, but is also capable of emitting various harmonic frequencies of the crystal for use as check frequencies. These checkpoints are then used for adjusting the heterodyne oscillator, thus insuring more accurate operation. Provisions are usually made within the crystal-controlled oscillator for precise adjustment to its assigned fundamental frequency.

Wavemeters

Wavemeters are calibrated resonant circuits used to measure frequency. Although the accuracy of wavemeters is not as high as that of heterodyne frequency meters, they have the advantage of being comparatively simple and can be easily carried about.

Any type of resonant circuit may be used in wavemeter applications. The exact kind of circuit employed depends on the frequency range for which the meter is intended. Resonant circuits consisting of coils and capacitors are used for low-frequency wavemeters. Butterfly circuits, adjustable transmission line sections, and resonant cavities are used in VHF and microwave instruments.

There are three basic kinds of wavemeters—the absorption, the reaction, and the transmission types.

Absorption wavemeters are composed of the basic resonant circuit, a rectifier, and a meter for indicating the amount of current induced into the wavemeter. In use, this type of wavemeter is loosely coupled to the circuit to be measured. The resonant circuit of the wavemeter is then adjusted until the current meter shows a maximum deflection. The frequency of the circuit under test is then determined from the calibrated dial of the wavemeter.

The reaction type derives its name from the fact that it is adjusted until a marked reaction occurs in the circuit being measured. For example, the wavemeter is loosely coupled to the grid circuit of an oscillator, and the resonant circuit of the meter is adjusted until it is in resonance with the oscillator frequency.

The setting of the wavemeter dial is made by observing the grid current meter in the oscillator. At resonance, the wavemeter circuit takes energy from the oscillator, causing the grid current to dip sharply. The frequency of the oscillator is then determined from the calibrated dial of the wavemeter.

This type is commonly referred to as a "grid-dip" meter, and is discussed in Basic Electronics.

The transmission wavemeter is an adjustable coupling link. When it is inserted between a source of radiofrequency energy and an indicator, energy is transmitted to the indicator only when the wavemeter is tuned to the frequency of the source. Transmission wavemeters are widely used in measuring microwave frequencies. Units of this type are included in echo boxes. The additional provisions for echo boxes permit additional testing functions.

Many actual wavemeters are used in performing various functions. Cavity-type wavemeters are the type most commonly used, and only this type is discussed in detail.

Cavity Wavemeters

Figure 17-16 shows a typical cavity wavemeter. The wavemeter illustrated is of the

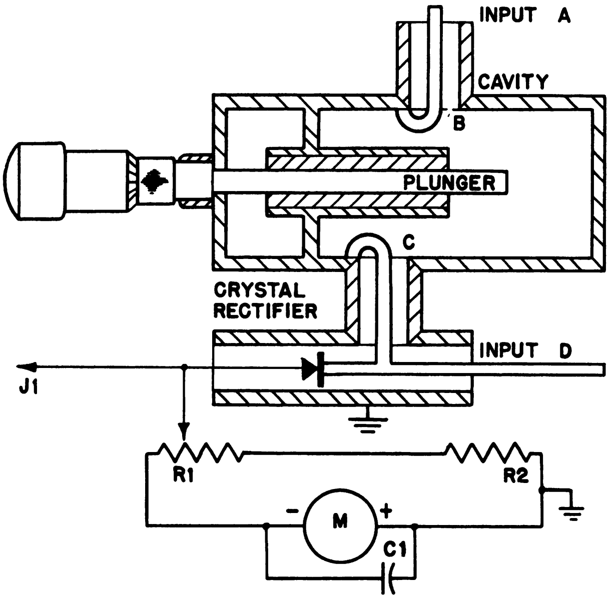

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Figure 17-16.—Typical cavity wavemeter.

type commonly used for the measurement of microwave frequencies. The device employs a resonant cavity which effectively acts as a high-Q, LC tank circuit. The resonant frequency of the cavity is varied by means of a plunger which is mechanically connected to a micrometer mechanism. Movement of the plunger into the cavity reduces the cavity size and increases the resonant frequency. Conversely, an increase in the size of the cavity (made by withdrawing the plunger) lowers the resonant frequency. The microwave energy from the equipment under test is fed into the wavemeter through one of two inputs, A or D. A crystal rectifier then detects (rectifies) the signal, and the rectified current is indicated on the current meter, M.

This specific instrument can be used as either a transmission type or an absorption type wavemeter. When used as a transmission wavemeter, the unknown signal is coupled into the circuit by means of input A. When the cavity is tuned to the resonant frequency of the signal, energy is coupled through coupling loop B into the cavity and out through loop C to the crystal rectifier. It is rectified and current flow resulting from this rectification is indicated on the meter. At frequencies off resonance, little or no current flows in the detector and the meter reading is small. The micrometer and attached plunger are varied until a maximum meter reading is obtained. The micrometer setting is then compared with a calibration chart supplied with the wavemeter to determine the unknown frequency.

When the unknown signal is relatively weak, such as the signal from a klystron oscillator, the wavemeter is usually used as an absorption type of device. Connection is made to the instrument at the input D. The RF loop C then acts as an injection loop to the cavity. When the cavity is tuned to the resonant frequency of the klystron, maximum energy is absorbed by the cavity and the meter dips, indicating a reduction of current. When the cavity is not tuned to the frequency of the klystron, high current is indicated on the current meter. Therefore, the cavity is tuned for a minimum reading, or dip, in the meter; and the resonant frequency is determined from the micrometer setting and the calibration chart.

Potentiometer R1 is used to adjust the sensitivity of the meter from the front panel of the instrument. J1 is a video jack and is provided for observing video waveforms with a test oscilloscope.

A directional antenna is used in conjunction with the instrument for making relative field strength measurements of radiated signals, for use in measuring the frequency of radar transmitters, and for constructing radiation patterns of transmitting antennas.

In radiation pattern measurements, the directional antenna is connected to the wavemeter input, and the instrument is tuned to the frequency of the system under test. The cavity is then locked on this frequency by an AFC system. The output signal being measured must be continuous and constant for reliable results. This is necessary in order for any variation in the meter reading to be caused directly by a change in the actual field strength of the signal when the position of the wavemeter is changed with respect to the transmitting antenna. After establishing a reference level on the meter, the position of the wavemeter is then changed by moving it around the radiating antenna, maintaining a fixed distance from it. The wavemeter readings at various positions around the transmitting equipment are recorded on polar graph paper, and the field pattern is thereby determined.

COUNTER TYPE FREQUENCY METER

The counter type of frequency meter is a high-speed electronic counter, with an accurate, crystal-controlled time base. This type of combination provides a frequency meter which automatically counts and displays the number of events (hertz) occurring in a precise time interval. The frequency meter itself does not generate any signal, but merely counts the recurring pulses fed to it.

Electronic Counter 524D

A counter type frequency meter (fig. 17-17), Electronic Counter 524D (Hewlett-Packard), can measure frequencies from 10 Hz to 10.1 MHz and display the readings in digital form on an eight-place indicating system. In addition to making direct frequency measurements, they can measure periods (0 Hz to 100 kHz), frequency ratios, and total events. A self-check feature enables an operator to verify instrument operation for most types of measurements. The internal oscillator is stable within 5 parts of 10^8 per week. Thus these counters make good secondary frequency standards.

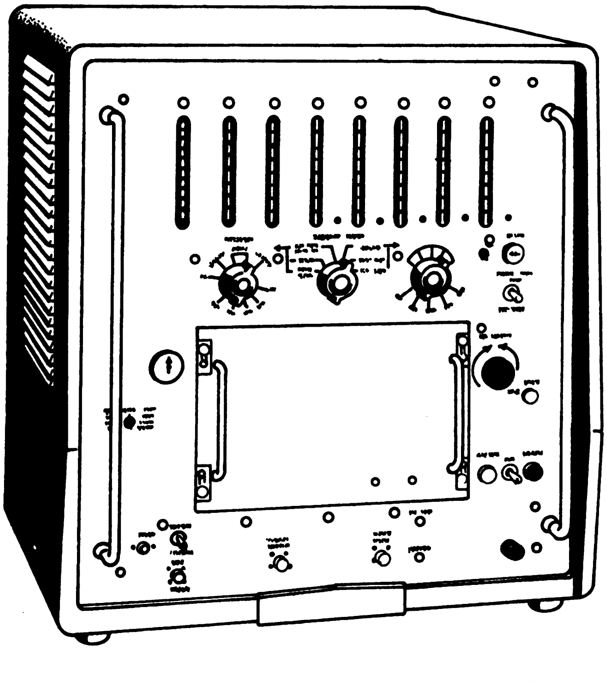

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Figure 17-17.—Electronic counter, 524D.

To increase the range of measurement, seven accessory plug-in units (not shown) are available. Frequency Converter Units, Models 525A, B, and C, increase the frequency range from 10.1 MHz to 100 MHz, 100 MHz to 220 MHz, and 100 MHz to 510 MHz, respectively. Video Amplifier unit 526A increases the basic set sensitivity to 10 mv in the range of from 10 Hz to 10.1 MHz; Time Interval unit 526B permits measuring time intervals from 1 μsec to 10^7 seconds; Period Multiplier unit 526C extends the period measurement range up to 10,000 periods of unknown frequency; and Phase unit 526D permits measuring phase angle with an accuracy approaching ±0.1°. In addition to the plug-ins, the Model 540B Transfer Oscillator extends, as a companion instrument, the frequency range up to 12.4 megahertz (10^9 accuracy).

To measure frequency the basic circuit arrangement of the electronic counter is shown in figure 17-18. For frequency measurement the signal is fed through a Signal Gate to a series of digital type counters. A precision time interval obtained from the Time Base Section opens and closes the Signal Gate for an extremely accurate period of time, for example, 1 second. The counters count the number of hertz entering through the gate during the 1-second interval and then display the total. The answer is read directly as the number of kilohertz occurring during the 1-second interval. The period of time the Signal Gate remains open is set by the FREQUENCY UNIT switch (not shown). For each position of the FREQUENCY UNIT switch the illuminated decimal point is automatically positioned so that the answer is always read directly in kilohertz. The answer is automatically displayed for a period of time determined by gate time or the setting of the DISPLAY TIME control on the front panel, whichever is greater.

To measure a period or time interval the application of the two signals reverses as shown by the dotted lines in figure 17-18. The period or time interval to be measured is connected to open and close the Signal Gate while one of the standard frequencies from the Time Base Section is passed through the Signal Gate to the counters. When measuring period, one cycle of the incoming signal opens the gate, the next cycle closes it. The number of hertz of the standard frequency from the Time Base that occurred during the period are then indicated on the counters. The standard frequencies

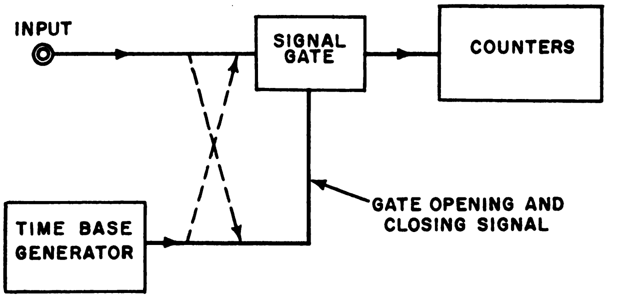

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Figure 17-18.—Basic block diagram of the 524D.

obtained from the Time Base have been selected so that the answer to the measured period will always be displayed in direct-reading units of time: seconds, milliseconds, or microseconds.

Provision is also made in the circuit to permit measurement of the average of 10 periods of the unknown frequency. Higher accuracy can thus be obtained than with single period measurements.

The accuracy of frequency measurements is determined by an internal oscillator and by a possible error of ±1 count that is inherent in the gate and counter type of instrument. At low frequencies, greater accuracy can be obtained by measuring the period of the signal than by measuring the frequency directly.

The block diagram (fig. 17-19 (A)) shows the circuit arrangement of the basic counter when measuring frequencies in the range of 10 Hz to 10.1 MHz. To measure frequencies up to 510 MHz, one of three frequency converter units is required (fig. 17-19 (B)). As stated above, the 525C Frequency Converter unit is used between 100 and 510 MHz. In these frequency converters the input signal is mixed with a harmonic of 10 MHz so that the difference between the signal and the harmonic is not more than 10.1 MHz. The difference frequency is counted and displayed. By adding the count displayed by the counter to the known 10 MHz harmonic the input signal frequency is determined.

All three frequency converters have tuning systems to indicate the correct mixing frequency. However, if the mixing frequency is within 1 MHz of the unknown frequency, there is a possibility of two answers, for you may not know whether to add or subtract the displayed reading from the mixing frequency. In such cases, make additional measurements using the two adjacent mixing frequencies to determine the unknown frequency. When making the final measurement choose a mixing frequency which is at least 100 kHz away from the unknown.

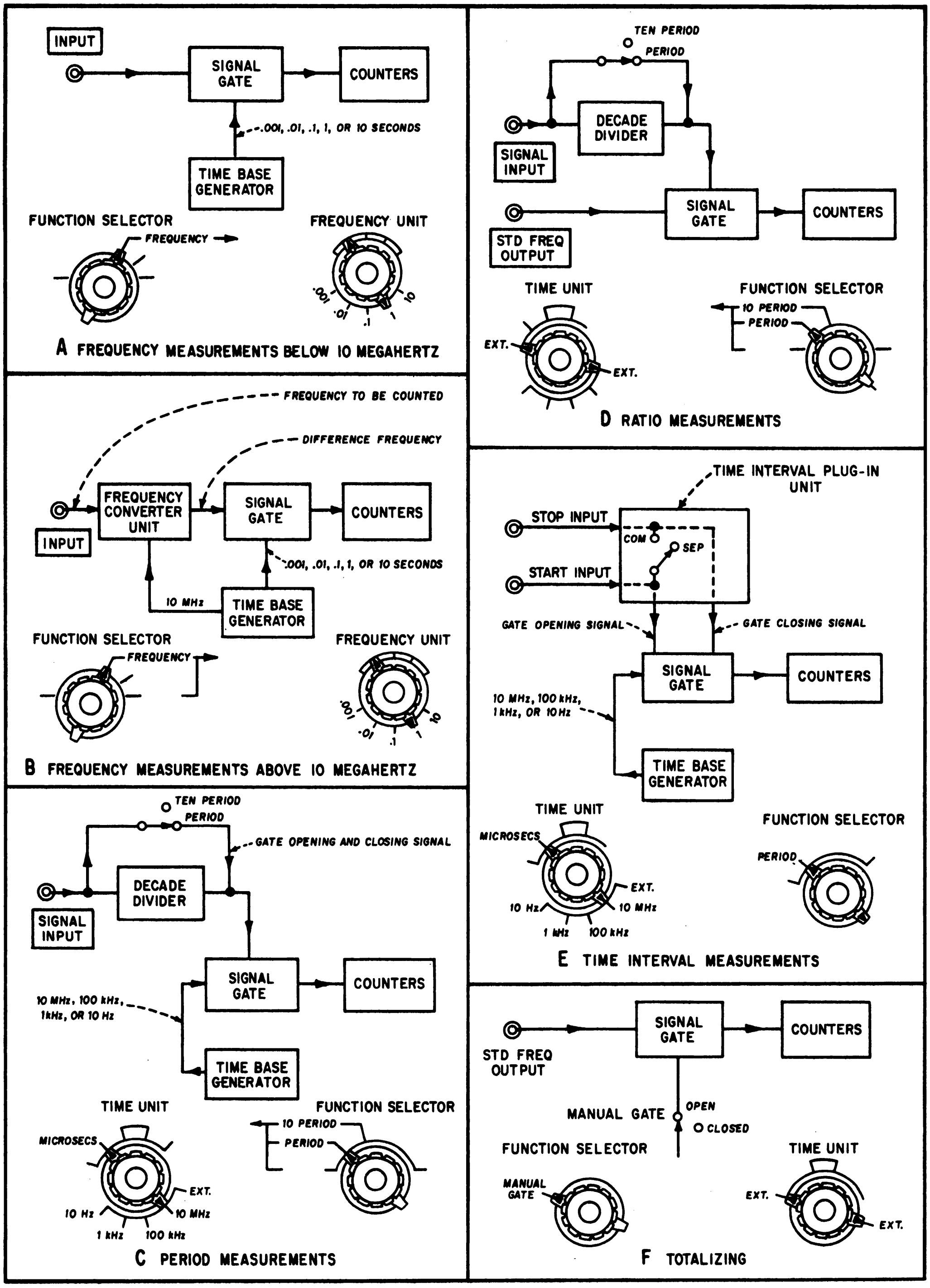
When measuring frequency, the counter will count sine waves, rectangular waves, and positive pulses. To measure the frequency of negative pulses, adjustment of a **FREQUENCY** sensitivity control is necessary. This control is a screwdriver adjustment located on the front panel.

When the counter is set for **PERIOD** measurements, the time base and the signal input circuits are interchanged from their frequency measurement positions (fig. 17-19 (C)). With the circuits so connected, the counters count the output of the time base for the period of the unknown input signal. Thus the standard frequencies generated in the time base are used as units of time to measure the unknown period in terms of microseconds, milliseconds, or seconds.

The accuracy of period measurements is largely determined by the accuracy with which triggering occurs at the same point on consecutive cycles of signal voltages having a slow rate-of-rise. Note that when the signal-to-noise ratio improves, the triggering accuracy also improves. Averaged over 10 periods, the single-period error is reduced by a factor of 10. If the 526C Period Multiplier unit is used, the error is reduced an additional factor of 10 for each factor the measurement is extended. The accuracy of triggering is considerably improved when the waveforms being measured have a fast rise time. For example, a significant reduction in error can be obtained if square waves are applied instead of sine waves to the input.

In order to follow the slowest-changing waveforms, the period measurement input circuits are direct-coupled and are adjusted to trigger at the zero-volt crossing of a negative-going voltage. Thus any d-c component in the input signal will shift the triggering level so that the maximum slope no longer occurs at the zero-volt level, resulting in a loss of accuracy. If the d-c component is large enough, there may be no triggering at all. An external generator can be used in place of the time base generator for period measurements.

The counter can be used to measure the **RATIO** of two frequencies. The higher frequency



A FREQUENCY MEASUREMENTS BELOW 10 MEGAHERTZ

B FREQUENCY MEASUREMENTS ABOVE 10 MEGAHERTZ

C PERIOD MEASUREMENTS

D RATIO MEASUREMENTS

E TIME INTERVAL MEASUREMENTS

F TOTALIZING

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Figure 17-19.—Test measurement, block diagram

is passed through the signal gate to the counters and is counted for a period of time determined by either one period or 10 periods of the lower frequency, which controls the opening and closing of the gate (fig. 17-19 (D)).

Ratio measurement accuracy is determined by the same factors as period measurement accuracy: consistency of triggering by the lower input frequency and the inherent error of ±1 count of the higher frequency. The 526C Period Multiplier unit is used to reduce the error by extending the number of periods of the lower frequency over which the measurement is made. For each factor of 10 the measurement is extended, the error is decreased by a factor of 10.

Although the time base generator is not used during ratio measurements, ratio measurements cannot be made if the time base generator is not operating. The counter has a holdoff circuit which disables the signal gate if the time base generator fails.

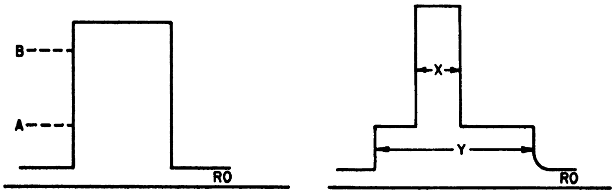
To make TIME INTERVAL measurements (fig. 17-19 (E)), the 526B time interval unit must be installed. Time interval measurements are similar to period measurements except that the points on the signal waveforms at which the measurement starts and stops are adjustable. The adjustable threshold feature allows you to make measurements from one part of the same waveform or to use separate waveforms as start and stop signals.

As in the case of period measurements, the input signals control the opening and closing of the gate while the standard frequencies are passed to the counters (fig. 17-19 (E)). Thus the accurate frequencies generated in the time base are used as units of time to measure the unknown interval in terms of microseconds, milliseconds, or seconds.

The 526B time interval unit may also be used as a high-speed totalizer capable of counting at a maximum rate of 10.1 million events per second. The basic circuit arrangement is indicated in figure 17-19 (F).

The threshold-selecting controls adjust the start and stop channels so that they will be actuated only by signals of predetermined polarity, amplitude, and slope. Time interval measurements begin when the start signal crosses the selected start threshold value in the selected direction and end when the stop signal crosses the selected stop threshold value in the selected direction. The threshold controls are only approximately calibrated and in some applications, special precautions will have to be taken in order to obtain the desired interval.

If an uncomplicated waveform is used as the start and/or stop signal, the setting of the threshold controls is not critical. For example, if a sharp pulse like that shown in figure 17-20 (A) is used, there will be little difference whether the measurement begins at point A or B. However, if a more complex waveform like that shown in figure 17-20 (B) is used to measure the interval X, set the threshold controls near zero as a preliminary adjustment. As the start and then the stop threshold controls are adjusted notice the definite changes in the measured time interval. Thus the start and stop thresholds are above the step and the indicated time interval is actually X.



A SIMPLE WAVEFORM SHOWING TWO POSSIBLE VOLTAGE LEVELS AT WHICH A TIME INTERVAL MEASUREMENT MAY BE STARTED

B TWO POSSIBLE TIME INTERVAL MEASUREMENTS OF A SINGLE COMPLEX WAVEFORM

AQ.589

Figure 17-20.—Time interval waveforms.

It is highly desirable to examine both start and stop signals on a d-c coupled oscilloscope before attempting a measurement. In this way it can be determined that no spurious signals exist, and the threshold controls can be carefully set.

With a 526D phase unit plugged into the counter, the phase angle between two signals of identical frequency, in the range from 1 Hz to 20 kHz, may be measured. This unit is useful for investigating, at various points in a circuit, the phase a signal has with respect to the phase it had at the input. Connect the reference signal to the REFERENCE INPUT, and the signal whose phase is under investigation to the UNKNOWN INPUT. If the frequency of the signal is 400 ± 4 Hz phase angle is read directly in tenths of a degree. For a signal of some other frequency in the rated range, the information is read in time units, with resolution up to 0.1 μsec. For all phase measurements, set the phase unit PHASE/PERIOD switch to PHASE, the REFERENCE LEAD/LAG switch to the type of measurement desired, and the counter FUNCTION SELECTOR to PERIOD.

In general, circuit action for a Phase measurement is similar to that for a time interval measurement. Trigger circuits in the phase unit supply the pulses which open and close the signal gate in the counter. Arrangement of the circuits will be similar to that shown in figure 17-19 (E), for the time interval measurements.

Digital Readout Electronic Counter AN/USM-207

The AN/USM-207 is a portable, solid-state electronic counter for precisely measuring and displaying on an 9-digit numerical readout the frequency and period of a cyclic electrical signal, the frequency ratio of two signals, the time interval between two points on the same or different signals, and the total number of electrical impulses (totalizing). The counter also provides the following types of output signals:

1. Standard signals from 0.1 Hz to 10 MHz decade steps derived from a 1-MHz frequency standard, frequency dividers, and a frequency multiplier;
2. Input signals divided in frequency by factors from 10 to 10^8 by a frequency divider;
3. Digital data of the measurement in four-line binary-coded-decimal form with decimal point and control signals for operation of printers, data recorders, or control devices; and
4. A 1-MHz output from a frequency standard.

The AN/USM-207 (figure 17-21) consists of a major counter assembly, two plug-in assemblies which install in recesses on the front and rear panel, and a group of accessory cables and connectors stored in the detachable front cover.

The major assembly Digital Readout Electronic Counter CP-814/USM-207 contains the input amplifiers; gate control; display; reset and transfer control; frequency multipliers;

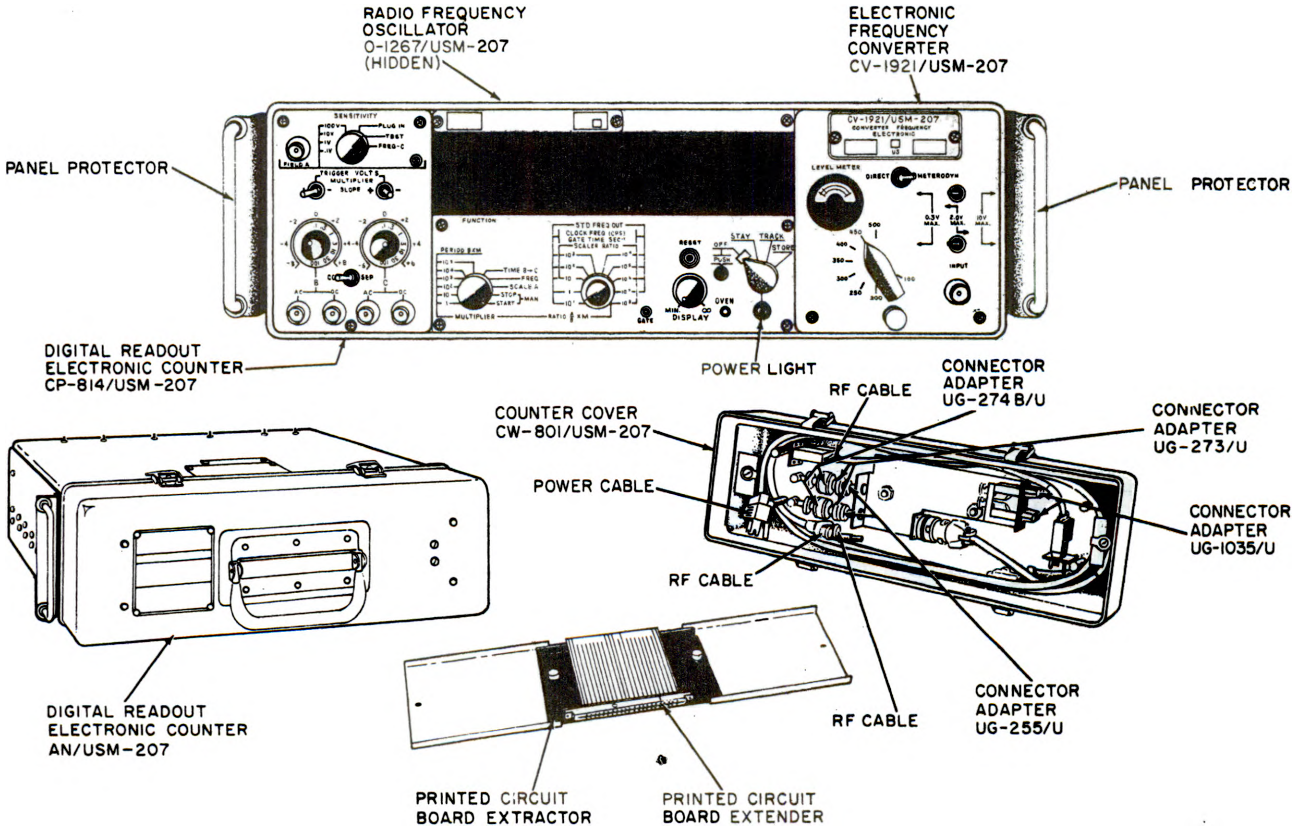


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Figure 17-21.—Digital readout electronic counter AN/USM-207.

time base dividers; decade and readout boards; numerical display tubes; decimal point and units indicators; power supply and regulator; and controls associated with these circuits.

The Radiofrequency Oscillator O-1267/USM-207 plug-in assembly develops a 1-MHz signal and includes its own power supply. The oscillator includes the 1-MHz output receptacle which may be used as a source of that frequency when the oscillator is connected to a-c power through the basic counter or when connected to the power line independently of the counter. The counter may be operated without the oscillator in totalizing, scaling the input signal, time interval with external clock, and frequency ratio measurements. For other measurements the counter does not require the oscillator when a separate external 100 kHz or 1 MHz signal is connected. In either of these two situations the oscillator may be left in the counter or removed. The oscillator plugs into the right rear of the counter.

The Electronic Frequency Converter CV-1921/USM-207 plug-in assembly permits measurement of frequencies up to 500 MHz using the heterodyne principle. The unit consists of the broadband amplifier, mixer, multiplier, and controls and indicators associated with these circuits. When measurements other than heterodyne frequency measurements are made, the converter is not required, but need not be removed. The converter also permits the measurement of signals from 35 MHz to 100 MHz with a greater sensitivity than available with the basic counter. The converter plugs into the right front of the counter.

Figure 17-22 is the overall functional block diagram of the counter. To make a measurement, requires two types of information; a count signal, and a gate control signal. These

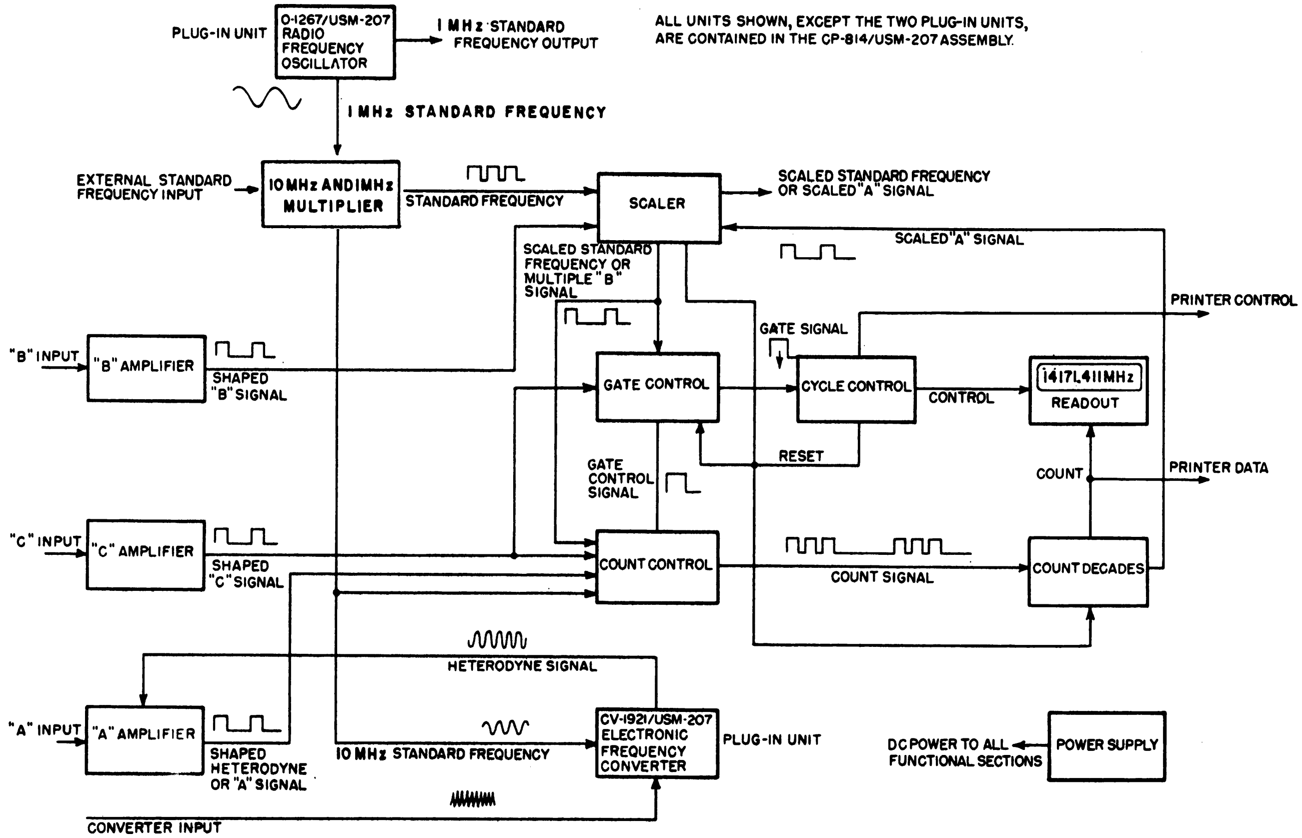
PLUG-IN UNIT
O-1267/USM-207 RADIO FREQUENCY OSCILLATOR
1 MHz STANDARD FREQUENCY OUTPUT
ALL UNITS SHOWN, EXCEPT THE TWO PLUG-IN UNITS, ARE CONTAINED IN THE CP-814/USM-207 ASSEMBLY.
1 MHz STANDARD FREQUENCY
EXTERNAL STANDARD FREQUENCY INPUT
10 MHz AND 1 MHz MULTIPLIER
STANDARD FREQUENCY
SCALER
SCALED STANDARD FREQUENCY OR SCALED "A" SIGNAL
SCALED "A" SIGNAL
SCALED STANDARD FREQUENCY OR MULTIPLE "B" SIGNAL
PRINTER CONTROL
GATE SIGNAL
"B" INPUT
"B" AMPLIFIER
SHAPED "B" SIGNAL
GATE CONTROL
CYCLE CONTROL
CONTROL
1417L411MHz
READOUT
RESET
GATE CONTROL SIGNAL
COUNT
PRINTER DATA
"C" INPUT
"C" AMPLIFIER
SHAPED "C" SIGNAL
COUNT CONTROL
COUNT SIGNAL
COUNT DECADES
HETERODYNE SIGNAL
"A" INPUT
"A" AMPLIFIER
SHAPED HETERODYNE OR "A" SIGNAL
10 MHz STANDARD FREQUENCY
CV-1921/USM-207 ELECTRONIC FREQUENCY CONVERTER
PLUG-IN UNIT
DC POWER TO ALL FUNCTIONAL SECTIONS
POWER SUPPLY
CONVERTER INPUT

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Figure 17-22.—Digital readout electronic counter AN/USM-207 overall functional block diagram.

two signals may be generated within the instrument or they may be supplied from outside sources. The type of measurement the counter will make depends upon the relationship of these two signals. In any function the instrument counts the count signal for a period of time determined by the gate control signal. Routing of these signals within the instrument is accomplished by logic circuits. These logic circuits are controlled by means of the front panel controls.

The radiofrequency oscillator (O-1267/USM-207) generates a signal of precise frequency for use throughout the counter or to provide a precise 1 MHz signal for use outside the equipment.

The electronic frequency converter accepts radiofrequencies between 100 MHz and 500 MHz and converts them to radiofrequencies between 5 MHz and 100 MHz for measurement by the basic counter.

The "A" amplifier amplifies the A input signal or the output of the converter for use throughout the counter.

The "B" amplifier amplifies and shapes the B input signal for use throughout the counter.

The "C" amplifier amplifies and shapes the C input signal for use throughout the counter.

The 10 MHz and 1 MHz multiplier multiplies the frequency and shapes the signal generated by the radiofrequency oscillator. It also provides precise timing signals to the various functional sections of the basic counter and to the frequency converter.

The scaler consists of a series of decade dividers and gating systems which provide divided standard frequencies and control signals depending on the type of measurement the instrument is making.

The gate control generates the gate control signal. This signal determines the length of time that the count decades will count the count signal.

The count control provides the proper count signal to the count decades, as selected by the setting of the front-panel switches.

The cycle control produces all signals necessary to display the measurement results on the readout and to recycle the counter.

The count decades count the count signal when permitted to do so by the gate control. The result of their counting becomes the final reading displayed by the readout at the end of each measurement.

The readout receives binary-coded-decimal (BCD) data from the count decades, decodes this data into decimal form and drives the readout indicator tubes. The readout also contains memory circuits which function when the counter is operated in the "Store" mode.

The power supply supplies all d-c power required by the basic instrument and the converters and consists of seven d-c supplies. Five of these supplies (+18 volt, +12 volt, +6 volt, and -12 volt) are regulated and two (+180 volt and +45 volt) are unregulated.

Frequency Meter AN/USM-26

Frequency Meter AN/USM-26 is a precision instrument that automatically measures frequencies to 100 MHz and automatically displays its measurements in digital form on an 8-place panel indicating system. In addition to making direct measurements of frequency, the AN/USM-26 also measures period (time of one cycle of periodic wave), time intervals, and frequency ratios, and may be used to count random events such as those encountered in nuclear work. The equipment further includes a self-check feature that enables the operator to verify the proper operation of the equipment for most types of measurements.

By use of the Frequency Converter AN/USA-5 plug-in unit, the useful operating range of the USM-26 is extended to 220 MHz. Similarly, using the Transfer Oscillator CM-102/USM-73 in conjunction with the USA-5 further extends the frequency range to the vicinity of 5 GHz (gigahertz) before the harmonics become too weak for use. Use of a tunable detector allows the operator to resonate the signal to be measured, thus increasing the sensitivity of the equipment for detection of harmonics. This extends the upper limit of operation to about 12 GHz. A second tunable detector can be used to further increase the sensitivity by resonating the desired harmonic produced by the transfer oscillator.

Because of the accuracy with which it measures frequencies, the USM-26 equipment can be considered to be a new type of secondary frequency standard that replaces more elaborate installations of conventional precision frequency-measuring equipment. Other typical frequency-measuring applications for the equipment include calibration of transmitters, oscillators, signal generators, etc.

Time measurements that the equipment will make include pulse length, pulse interval, time delay, etc.

Since the indicating system in the equipment presents the measured frequency in as many as eight significant figures, the equipment is especially useful for measuring very small frequency changes such as are encountered when making measurements of frequency stability of oscillators and similar frequency generators.

POWER MEASUREMENTS

It is often necessary to check the power consumption and the input and output signal power levels of electronic equipment. The determination of d-c power is comparatively simple; the unit of power (the watt) is the product of the potential in volts and the current in amperes. Therefore, a few basic circuit measurements may be taken and the power computed by means of Ohm's law.

To make accurate a-c power measurements, the phase angle of the voltage and current must be considered. The measurement of a-c power is further complicated by the frequency limitations of various power meters. If there is no phase difference, a-c power may be computed in the same manner as d-c power, by determining the average value of the product of the voltage and current.

Electric power at a line frequency of approximately 60 Hz may be measured directly by a dynamometer type wattmeter. This type of meter (discussed in Basic Electricity) indicates the actual power; and therefore, the phase angle of the voltage and current does not have to be determined. Normally, the exact power consumption of equipment is not necessary for maintenance, and a current measurement is sufficient to decide whether the power consumption is within reason.

Many a-c voltmeters have scales calibrated in decibels or volume units. Such meters are useful for making measurements where direct indication in decibels is desired. However, it must be remembered that these are voltmeters, and that power measurements are not meaningful unless the circuit impedance is known. (The topic of decibels is discussed in some detail in Basic Electronics.)

At radiofrequencies below the UHF range, power is usually determined by voltage, current, and impedance measurements. One common method, used to determine the output power of RF oscillators and radio transmitters, consists of connecting a known resistance to the equipment output terminals, measuring the current flow through the resistance, and then calculating the power as the product of I^2R. Since the power is proportional to the current squared, the meter scale can be calibrated to indicate power units directly. A thermocouple ammeter is usually used for measurement of RF current. The resistor used to replace the normal load is usually specially designed to have low reactance, and has the ability to dissipate the required amount of power. Such resistors are commonly called "dummy loads" or "dummy antennas."

In the UHF and SHF portion of the radiofrequency spectrum, it is usually difficult to accurately measure the voltage, current, and impedance. These basic measurements may change greatly at slightly different points in a circuit, and are appreciably affected by small changes in the placement of parts in the vicinity of the tuned circuits. To measure the output of microwave radio or radar transmitters, test instruments which convert RF power to another form of energy, such as light or heat, can be used to indirectly measure the power. A method which measures the heating effect of a resistor load on a stream of passing air can be used. Accurate measurement of large magnitude power can be achieved by measuring the temperature change of a water load. The most common type of power meter for use in this frequency range employs a bolometer. The bolometer is a loading device that undergoes changes of resistance as changes in the power dissipation occur. Resistance is measured before and after RF power is applied, and power can be determined by the change in resistance.

COMPONENT TESTERS

This section discusses the testing of components considered to be most essential in any electronic circuit. These components include the transistor, crystal diode, and the electron tube. During the process of maintaining the equipment for which the technician is responsible, these three particular components are the ones with which he becomes most involved.

ELECTRON TUBE TESTER

Before discussing the testing of electron tubes on the tube tester, the substitution method of testing is described.

Substitution of a tube known to be good is a simple and the most reliable method of determining the quality of a questionable tube. Usually this method cannot be used to eliminate more than one tube in a single circuit. For instance, if both an RF amplifier and an IF amplifier are defective in a receiver, replacing either one does not correct the trouble. Also the practice of replacing several tubes in a circuit, all at one time, will usually result in misalinement of a tuned circuit. Under conditions such as these, the use of test equipment designed for testing the quality of a tube saves valuable time.

Experience has shown that tube failures may be roughly classified as follows: mechanical defects and gas within the tube, filament (or heater) burned out, change in tube characteristics, physical damage, and intermittent shorts. Mechanical defects and rise of gas pressure within the tubes are attributed to faulty construction and processing. Some of these defects cannot be detected by standard testing methods until the tubes have been in operation for some time. Filament burnout may be caused by repeated sudden application of full voltage to the filament. Initial heating of the filament is nonuniform. As a result, mechanical stresses due to thermal expansion are set up, and these stresses weaken the filament structure and hasten its failure.

Change in tube characteristics is a broad classification and covers decreasing emission, change in cutoff voltage, changing transconductance, etc. Such changes are usually the result of deterioration of the cathode structure, or formation of a cathode interface surface in the tube or changes in alinement of the electrode parts. Physical damage is largely accidental. It includes such causes as breakage, bending of pins, and inadvertent application of excessive voltages.

Two common types of tube-testing equipment are the emission tube tester and the transconductance tube tester. These types may also incorporate circuits for making important tests other than emission and transconductance. Several types of tests are described in the following paragraphs.

Emission Tube Tester

The emission tester measures the condition of the cathode emitting surface. The end of the useful life of a tube is usually preceded by a reduction in electron emissivity, that is, the cathode becomes unable to supply the number of electrons necessary for proper tube operation. Also, if the tube has an open element, the defect prevents proper emission, and the tester indicates it as a reject. Both multigrid and diode tubes are tested for cathode emission.

The emission tester has certain limitations and disadvantages. Since the manufacturer of a tube does not state a definite 100 percent emission point which could be used for reference, the emission test is not conclusive. High emission does not necessarily indicate a good tube, because this condition might be present in a tube with a faulty grid structure or one which has a highly emissive spot on its cathode. Very high emission has also been observed just before a tube fails completely; hence, fairly low emission does not necessarily indicate in all cases that a tube is near its end-of-life point.

A further disadvantage of the emission test is that gas is liberated within the tube when a-c test voltages are applied unless the test is made quickly. Also, because the tube is not tested with its circuit d-c electrode voltages in this test, it is not tested under actual operating conditions. It is also possible for a tube to show normal emission and still not operate properly. The reason for this is that the efficiency of a tube depends on the ability of the grid voltage to control the plate current. The emission type tester tests only the plate current developed, and not the ability of the grid to control the plate current. The transconductance type tester checks the latter characteristic.

Transconductance Tube Tester

The term transconductance (also called mutual conductance) expresses the effect of grid voltage upon the plate current of a tube. By measuring the transconductance of a tube it is possible to evaluate the condition of the tube much more accurately than by measuring its cathode emission, because this test more closely approximates actual circuit conditions.

Transconductance is expressed mathematically as the ratio of a change in plate current to a change (small) in control-grid voltage with all other electrode voltages held constant. Transconductance is measured in units of conductance called micromhos. The equation for transconductance is:

$$G_m = \frac{\Delta I_p}{\Delta E_g}$$

where G_m is the transconductance in micromhos, ΔI_p is the change in plate current in microamperes, and ΔE_g is the change in control-grid voltage. When the control-grid voltage changes 1 volt (positive or negative), the current change in microamperes is equal to the transconductance in micromhos. In other words, if an amplifier tube has a transconductance of 2,000 micromhos, a 1-volt change in the control-grid voltage will cause a plate-current change of 2,000 microamperes. The transconductance of a tube may be measured by two methods: one method is the static (d.c.) method and the other is the dynamic (a.c.) method.

STATIC METHOD.—In the static method (also called the "grid shift" method) of measuring transconductance, the d-c bias voltage on the control-grid of the tube under test is changed, and the resultant change in the steady plate current is measured with a current meter.

DYNAMIC METHOD.—The dynamic method of determining transconductance makes use of a circuit which applies an a-c signal to the control grid of the tube under test.

Operation of a Typical Tube Tester

The tube-testing equipment discussed in this section is a typical, general-purpose test equipment of the transconductance type. The TV-7/U tube tester (fig. 17-23) is representative of this type equipment.

The front-panel controls on this tester adjust (or switch) the various potentials necessary for the testing of tubes. The tube data chart (booktype) which is supplied with the equipment, lists the control setting for the various types of tubes generally encountered in the field.

CAUTION: Before the tube to be tested is inserted in the correct test socket, make certain that the front-panel controls are set to the positions listed for that type tube in the data chart. This precaution is necessary to prevent excessive voltage from being applied to the tube elements (especially the filament).

LINE VOLTAGE ADJUSTMENT AND TEST.—The line voltage adjustment is necessary so that the line voltage applied to the primary of the transformer can be preset to an operating value. A 93-volt potential is used as a test reference point, regardless of the variations caused by different tube loads or fluctuations in the a-c supply. Applied voltages may range from 105 to 130 volts and still be adjustable. Depressing the LINE TEST button connects the meter of the tube tester to read the "B" supply voltage. The test equipment is calibrated at the factory so that the meter pointer is approximately centered when the voltage across the primary is 93 volts. Since various types of electron tubes draw different values of currents, a LINE ADJUSTMENT rheostat (connected in series with the primary) is provided. The primary voltage can thus be set to the designed operating voltage before any test is begun. A small protective lamp which will burn out on overload is connected in series with the primary of the transformer to prevent equipment damage.

SHORT CIRCUIT AND NOISE TEST.—It is very important that the technician apply the test for short-circuited elements to a tube of doubtful quality before any other tests are made. This procedure protects the meter (or any other indicator) from damage. Also it follows logically that, if a tube under test has elements which are short-circuited, there is no further need to apply additional tests to that tube. Short-circuit tests are usually sensitive enough to indicate leakage resistance less than about one-fourth megohm. The proper heater voltage is applied so that any tube elements which might short as a result of the heating process will be detected. The short-circuit test is similar to the test used to detect noisy (microphonic) tubes caused by loose elements. The only difference between the two tests is in the sensitivity of the device used as an indicator.

GAS TEST.—In all electron tubes, except some types of rectifier tubes and thyratrons, the presence of any appreciable amount of gas is extremely undesirable. When gas is present, the electrons emitted by the cathode collide with the molecules of gas. As a result of these collisions, electrons (secondarily emitted) are dislodged from the gas molecules, and positive gas ions are formed. These ions are attracted by (and cluster around) the control grid of the tube, because it is negative (bias) and absorbs electrons from the grid circuit in order to revert to the more stable gas molecules (not ionized). If the amount of gas in the tube is appreciable, the collisions between the numerous gas molecules and the cathode-emitted electrons release many secondarily emitted electrons, and the resulting flow of grid current is high.

CATHODE LEAKAGE TEST.—The cathode element of an electron tube is essential because it supplies the electrons necessary for tube operation. Electrons are released from the cathode by means of some form of energy—generally heat—which is applied to it. An indirectly heated cathode consists of a heater wire (usually a tungsten alloy) enclosed in, but insulated from, a metal sleeve (nickel). This sleeve is coated with an electron emitting material (usually strontium or barium compounds) on its outer surface, and is heated by radiation and conduction from the heater. Useful emission does not take place from the heater wire.

When a tube which uses an indirectly heated cathode develops noise, it is almost a certain indication that a leakage path is present between the cathode sleeve and the heater wire. This assumption is justified because in the design of a tube the heater must be placed as close as possible to the cathode so that maximum tube efficiency is attained. Continual heating and cooling of the tube structure may cause small amounts of the insulation between the cathode and heater to become brittle or deteriorate, leaving a high-resistance leakage path between these elements. Under extreme conditions the insulation may shift enough to allow actual contact of the elements. Since the heater and cathode are seldom at the same potential, any form of leakage causes noise to develop in the tube.

The cathode normally is maintained at a higher positive potential, because cathode bias is the most common type of bias utilized. The heater circuit is usually grounded to chassis, either on one side of the filament supply or by a center-tap arrangement. Therefore, if a resistance path is present, a leakage current may flow from the heater to the cathode. Thus, in effect the cathode functions in the same manner as the plate of a tube; that is, it receives electrons. Assuming the existence of a high-resistance short, the current flow from the heater to the cathode will vary with any vibration of the tube because vibration varies the amount of resistance. If the cathode and heater are completely shorted (zero ohms), it is impossible for the tube to develop any cathode bias.

A cathode leakage test is sometimes made while a tube is being tested for short-circuited elements or noise. However, some tube-testing instruments incorporate the cathode leakage test as an additional test which is not part of the short-circuit test.

FILAMENT ACTIVITY TEST.—The filament activity test is used to determine the approximate remaining life of an electron tube insofar as the longevity of the cathode emitter is concerned. The test is based on the principle that the cathode in almost all electron tubes is so constructed that a decrease of 10 percent of the rated heater voltage causes no appreciable decrease in emission.

On a tube-testing equipment incorporating this test there is a two-position switch (FILAMENT ACTIVITY TEST) which has one position marked NORMAL and the other marked TEST. The switch remains in the NORMAL position for all tests other than the filament activity test. When the switch is set to the TEST position, the filament (or heater) voltage which is applied to the tube under test is reduced by 10 percent.

The filament activity test is performed as follows: After the quality test is made, the TUBE TEST button is held depressed, and the filament activity test switch is set to TEST position. If the indicator shows a decreased reading after a reasonable time is allowed for the cathode to cool, the useful life of the tube is nearing its end.

SEMICONDUCTOR TESTERS

The function of a crystal rectifier test set is to provide a quick and accurate means of testing a crystal rectifier in the field. Although the complete testing of a crystal rectifier is an elaborate procedure requiring precision radio-frequency test equipment, the test sets usually provided are sufficient for determining whether or not the crystal rectifier is satisfactory for use. Crystal testing is accomplished by measurement of the forward and backward resistance, and usually the back current at 1.0 volt.

A crystal rectifier is a device used for converting RF energy into unidirectional current. It usually consists of a small piece of silicon in contact with a thin tungsten wire (called a cat whisker), both of which are mounted in a small cartridge-type container. The rectification takes place at the contact between crystal and cat whisker, and is due to the fact that the resistance in one direction is greater than that in the other direction, as in a vacuum tube used

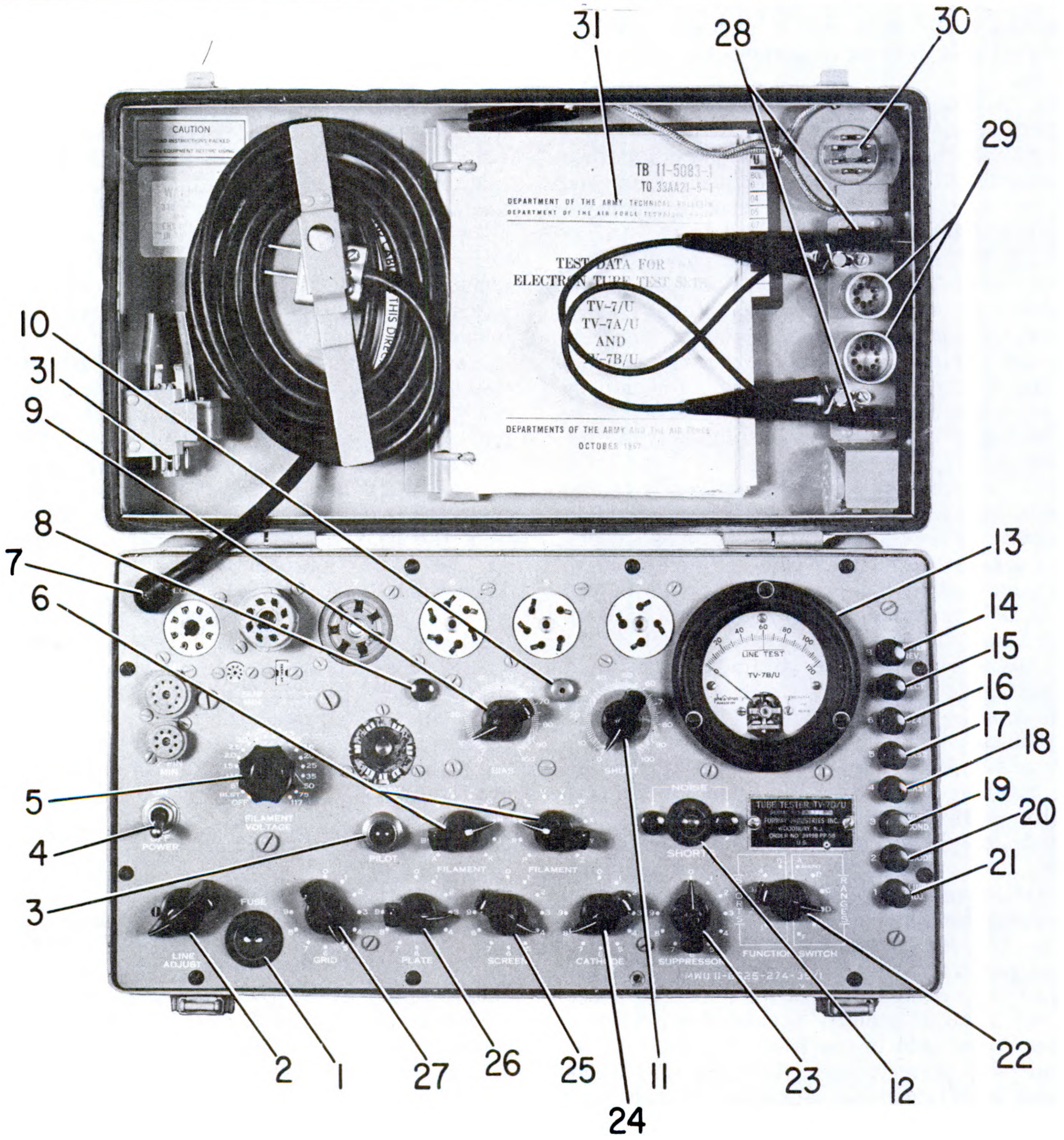

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Figure 17-23.—Electron tube test set TV-7/U.

as a rectifier or detector. The properties of the rectifier depend critically on the type of contact area, and the place of contact. The crystal rectifier has been carefully adjusted at the factory, and should not be upset by tampering with the setscrew.

A crystal rectifier is illustrated in figure 17-24. The crystal is designed so that current flows from the tip to the base (tungsten to silicon). The area of contact within the crystal rectifier housing is very small; and if too much current is passed through the cartridge, the

Nomenclature for figure 17-23.

1. Fuse lamp.
2. Line adj. control.
3. Pilot light.
4. Power switch.
5. Filament voltage.
6. Filament selectors.
7. A-C line cord.
8. Grid jack.
9. Bias control.
10. Plate jack.
11. Shunt control.
12. Neon lamp.
13. Meter.
14. Meter reverse switch.
15. Rectifier switch.
16. OZ4 switch.
17. Gas 2 switch.
18. Gas 1 switch.
19. Mut. Cond. switch.
20. Diode switch.
21. Line adj. switch.
22. Function switch.
23. Suppressor selector.
24. Cathode selector.
25. Screen selector.
26. Plate selector.
27. Grid selector.
28. Test leads.
29. Pin straighteners.
30. Adapter.
31. Test data book.

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resulting heat will damage it, causing the operation of the crystal rectifier to be impaired or possibly causing the unit to burn out completely.

Crystal rectifiers may be damaged by static discharges. The operator should be sure that any static charge which may be present on his body is discharged by momentarily touching (grounding) a finger to the ground contact of the test set or equipment in which the crystal is to be installed.

Because of the possibility of damage due to strong RF fields which may be present, crystal rectifiers are stowed in metal containers or in metal foil except when they are being tested or used.

The circuit diagrams of a typical crystal rectifier test set are illustrated in figures 17-25 and 17-26. The figures show two arrangements of the same device. The test set can be changed from the resistance measuring arrangement to the back current circuit by the action of a selector switch. The meter shown in the two figures is calibrated for both resistance and current measurements. It contains a 0-1 milliampere movement with an internal resistance of approximately 100 ohms.

The circuit shown in figure 17-25 is used for forward and backward resistance determination and is similar to the circuit of a simple ohmmeter. With switch S1 set to the ZERO ADJUST position, the milliammeter is first set for maximum (1.0 ma) current, or zero indicated resistance, by adjustment of the series

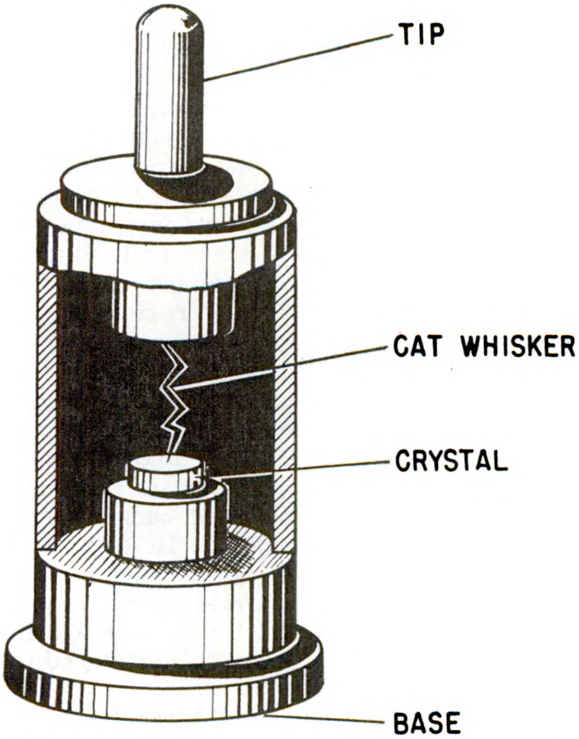

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Figure 17-24.—Crystal rectifier.

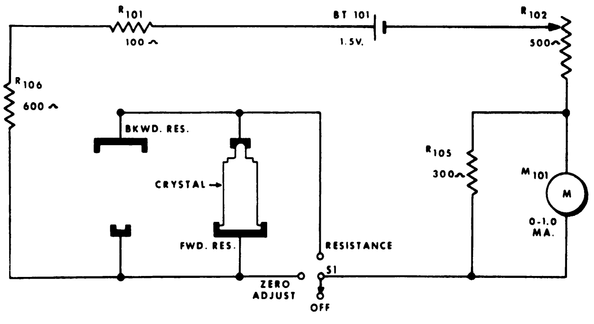

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Figure 17-25.—Rectifier test set schematic; resistance measurement configuration.

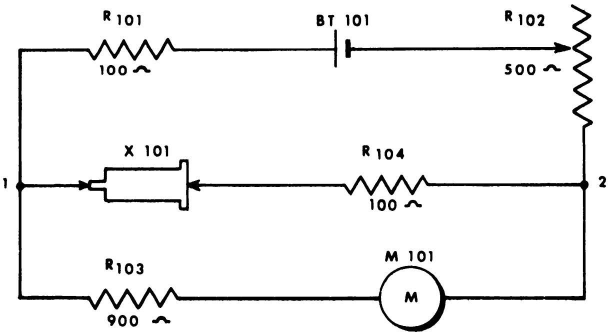
potentiometer R102. The forward and backward resistance can then be measured by rotating S1 to the appropriate position and placing the crystal rectifier in the proper holder. If no further change has been made in the position of the control R102, the additional resistance which the crystal rectifier introduces into the circuit causes a decrease in the current flow, and the meter will then deflect to some point on the scale other than full deflection.

The forward or "front," resistance of the crystal is the resistance measured with normal current flowing (comparable to the cathode-to-plate current flow in a diode vacuum tube). The crystal rectifier is considered unfit for use if this resistance is greater than 500 ohms.

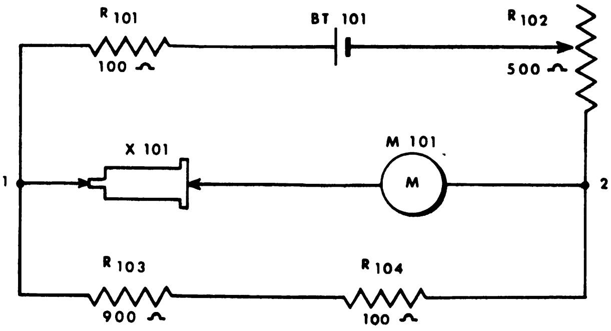
The backward, or "back," resistance of the crystal is a measure of resistance to current flow from the crystal to the whisker in the rectifier. This current flows from the rectifier base to the tip and is comparable to any current flowing from the plate to the cathode in a diode vacuum tube. The crystal rectifier should be rejected for use if the ratio of back resistance to front resistance is less than 10 to 1.

For example, if the meter reading is 400 ohms when the forward resistance is measured, then the back resistance must be 4,000 ohms or more if the crystal is considered to be usable.

In addition to the circuit arrangement for checking the resistance ratio of the crystal rectifier, many test sets are provided with means for measuring the back current through the rectifier with an applied voltage of 1.0 volt. This is a more accurate measure of the



(A) BACK CURRENT ZERO ADJUSTMENT



(B) BACK CURRENT

AQ.594

Figure 17-26.—Rectifier test set schematic; back current measurement configuration.

condition of the crystal than the resistance-ratio check. The circuit arrangements for this check are illustrated in figure 17-26. In (A) of the figure, the circuit is shown in the condition used for the initial voltage adjustment.

Before the back current is measured, the meter must be adjusted so that an effective voltage of 1.0 volt is impressed across points 1 and 2. Since the back resistance of a crystal rectifier is a high value, the effective resistance of the parallel circuit between points 1 and 2 in (A) of the figure is essentially that of the meter and R103, or 1,000 ohms. The full-scale reading of the milliammeter is 1.0 milliampere; therefore, an adjustment of R102 resulting in full-scale deflection of the meter insures a voltage of 1.0 volt across the parallel circuit.

After the voltage has been adjusted, the circuit is switched to the condition shown in (B) of figure 17-26 to measure the back current. In this condition, the position of M101 and R104 are exchanged so that the crystal is now in series with the milliammeter whose resistance is negligible compared with that of the rectifier. With 1.0 volt impressed across the circuit, the meter then indicates the current flowing through the crystal rectifier. The magnitude of this current is inversely proportional to the backward resistance of the crystal. The scale of the meter is usually marked to indicate the maximum limits of back current for the crystal rectifiers in common use.

The maximum allowable back current varies somewhat with temperature. The lower the temperature, the lower the maximum limit of back current. Temperature correction tables are included with the instruction manuals of most test sets. These should be consulted when the surrounding temperature is considerably lower or higher than 70°F (approximately 22°C).

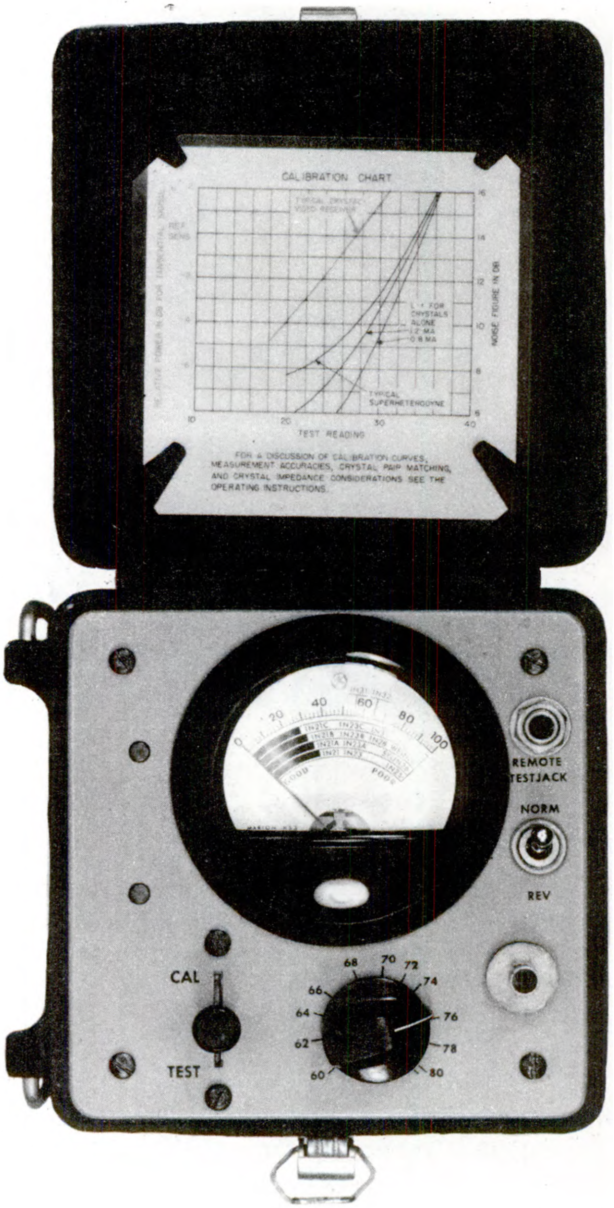
Figure 17-27 shows one type of crystal checker in use in the fleet. Important performance characteristics of crystals may be measured by this tester. These characteristics will largely determine the value of the crystals when used as detectors or mixers. The test set employs a technique using d-c voltage to measure quantities that are mathematically related to crystal performance. It may be used to measure the relative noise figure, obtain an impedance check for selecting matched crystals, and measure sensitivity of crystals.

The test set does not indicate effects of shunt capacity or RF impedance of crystals; however, these characteristics are small and are considered during manufacture of the crystals.

The instruction booklet issued with the test set has detailed explanations as to how the various crystal tests are performed. Also, a temperature correction chart and a chart of calibration curves are included. When exacting tests are to be made, it will be necessary to use the charts in the instruction booklet.

IN-CIRCUIT TRANSISTOR CHECKERS

Test Set, Transistor TS-1100/U (fig. 17-28) is designed to measure the beta parameter of a transistor when the transistor is connected in a circuit, and to measure beta and I_{CO} parameters with the transistor removed from the circuit.

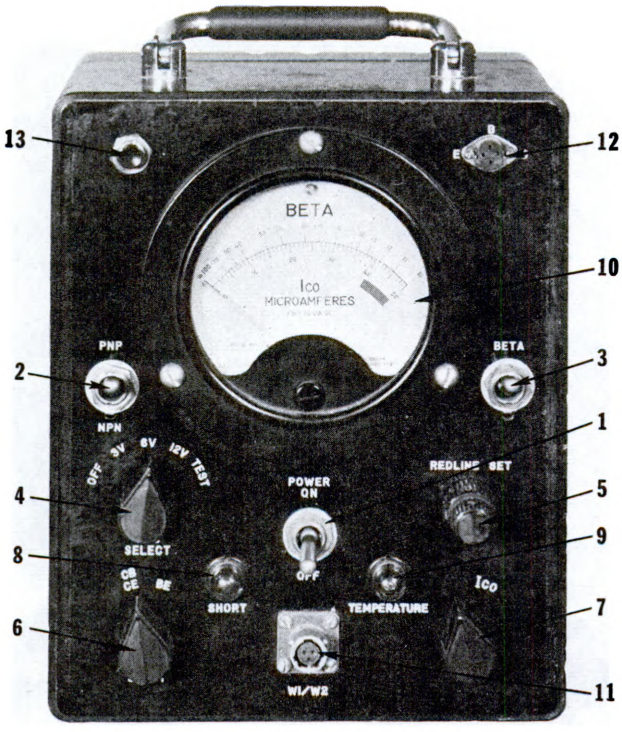

CALIBRATION CHART
TEST READING
NOISE FIGURE IN DB
TYPICAL SUPERHETERODYNE
FOR A DISCUSSION OF CALIBRATION CURVES, MEASUREMENT ACCURACIES, CRYSTAL PAIR MATCHING AND CRYSTAL IMPEDANCE CONSIDERATIONS SEE THE OPERATING INSTRUCTIONS
0
20
40
60
80
100
GOOD
POOR
REMOTE TESTJACK
NORM
REV
CAL
TEST
60
62
64
66
68
70
72
74
76
78
80

AT.111

Figure 17-27.—Model 21143 crystal checker.

The characteristics of the test set are:
1. Range of beta 10 to ∞ in a single band.
2. Leakage current measurements: 0 to 50 microamperes.
3. Temperature range: 0°C to +50°C.
4. Power supply: Battery operated.

The equipment contains two separate battery power supplies. One provides the power for the



AT.112

1. Power switch.
2. PNP/NPN switch.
3. Beta switch.
4. Bias select switch.
5. Red line set control.
6. Short switch.
7. I_{CO} switch.
8. Short indicator.
9. Temperature indicator.
10. Meter.
11. Probe connector.
12. Transistor socket.
13. Battery disconnect switch.

Figure 17-28.—Test set, Transistor TS-1100/U.

internal circuits, and the other furnishes the bias voltage required for the transistor under test. Either the mercury type or zinc-carbon batteries may be used for operation of the test set.

Low impedance techniques are used for measurement to isolate the transistor under test from the surrounding circuitry. The measurement accuracy of the tester is within ±20 percent provided that the loading of the emitter-base diode or the collector-base diode is not below 500 ohms, and the loading between the collector and the emitter is not below 500 ohms. If the emitter-base load contains a diode, the series impedance should not fall below 7,000 ohms to maintain this accuracy.

With the use of an appropriate shorting technique, the accuracy can be improved. The shorting technique consists of connecting a jumper wire between the emitter of the transistor under test and the far side of all components connected to the base electrode of the transistor. This technique is not universally applicable, and it should be employed only by skilled personnel.

The range of beta that can be measured is between 10 and ∞. A beta of infinity (∞) corresponds to zero microamperes on the readout meter scale. A transistor having a beta below 10 will cause the pointer of the meter on the tester to move off the scale. Because of the nonlinear characteristic of the meter scale, which causes crowding at the high end, the readout accuracy for betas above 100 is impaired.

The following controls, as seen on the front panel (fig. 17-28), are incorporated in the test set:

1. POWER switch (labeled ON-OFF): Turns the internal power source on or off.

2. PNP-NPN (transistor select) switch: Selects proper collector bias polarity for the type transistor under test.

3. BETA switch: Permits readout of beta.

4. BIAS SELECT switch: Used to set proper collector bias voltages (nominally 3, 6, or 12 volts). Also checks the condition of internal battery when in the TEST position.

5. RED LINE SET control: Adjusts the amplitude of the test signal.

6. SHORT switch (labeled CB, CE, BE): Enables measurement of a short circuit or a low impedance in the collector-base (CB), collector-emitter (CE), or base-emitter (BE) circuits.

7. I_{CO} switch: Enables readout of transistor leakage.

8. SHORT indicator: The indicator lamp will light when a short circuit or low impedance exists in either the transistor under test or in the surrounding circuitry. If the lamp lights, this indicates a load of less than 500 ohms.

9. TEMPERATURE indicator: The indicator lamp will light when the ambient temperature surrounding the equipment exceeds +50°C.

This indicates that the equipment is operating in an environment beyond that for which it has been designed, and that measurement inaccuracies will arise.

10. METER: Indicates magnitude of beta; indicates magnitude of I_{CO}; and indicates the condition of the internal battery. (The battery is good when the meter needle moves under the green band on the dial.)

11. PROBE connector: For connecting the cables (furnished with the test set) to the transistor to be tested.

12. TRANSISTOR socket (labeled E-B-C): Enables direct connection between the test set and transistor to be tested.

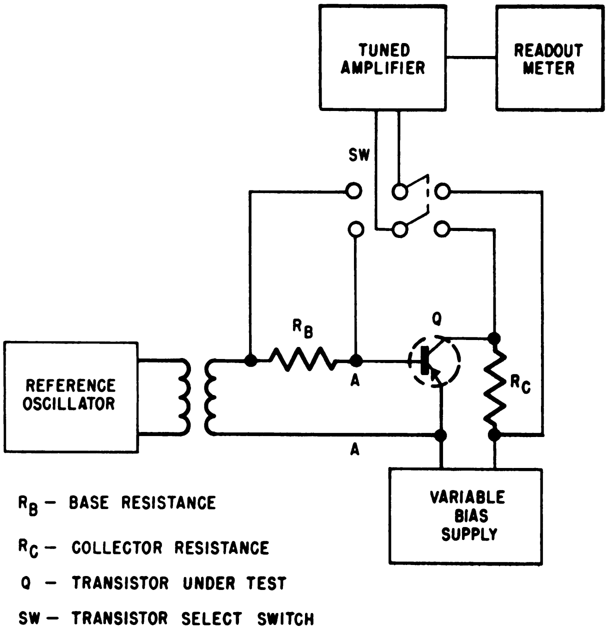
13. BATTERY DISCONNECT switch (upper left corner of panel—not labeled): Disconnects the internal battery when the front cover is snapped in place.

For proper procedure in operating the test set, refer to Technical Manual for Test Set Transistor TS-1100/U, NavShips 93277.

FUNCTIONAL DESCRIPTION.—The block diagram (fig. 17-29) consists essentially of a reference oscillator, a tuned amplifier, and a variable bias supply. The oscillator is used to generate a test signal, the tuned amplifier is used to measure the second harmonic component of the current of the transistor under test, and the bias circuit furnishes the appropriate voltages to the transistor under test.

The reference signal source is a Hartley oscillator operating at a frequency of 1,125 Hz. The transistor under test is biased for approximately class B operation. Thus, the transistor conducts only when the input signal level exceeds the work function of the emitter-base diode. The input signal is adjusted until the average collector current is 1 milliampere. The current passes through the collector load resistor, and a voltage is developed across it. This signal is first coupled through a high gain, narrowband amplifier, having a center frequency of 2,250 Hz, and then through a d-c microammeter. The amplifier gain has been adjusted so that the red line on the meter face corresponds to an average collector current of 1 milliampere.

The bandpass amplifier and meter are then switched across the base load resistor, and the meter then reads the magnitude of the average beta directly for a given transistor. Since the collector current is held constant for all transistors under test, the base current is inversely proportional to beta.



AT.113

Figure 17-29.—TS-1100/U, block diagram.

Direct measurement of the average collector and base current cannot be made on a d-c meter placed in series with these electrodes. This is because of the large errors which may result from the presence of "sneak paths" provided by the external network, since it is possible to have a direct current flow in these paths from the collector bias supply.

By making an a-c measurement, the problems of erroneous direct current are eliminated, but others are introduced. If the a-c components of the collector current and base current were measured without filtering, the readout meter would not be able to differentiate between the normally rectified signal of the transistor and a nonrectified signal caused by the a-c sneak paths. To eliminate these erroneous signals, the second harmonic component of the signal current is measured.

Octopus

The octopus is an electronic device used to troubleshoot deenergized printed circuit boards. It is designed for local construction and to locate defective components of printed boards quickly and safely without the necessity of removing component leads from the circuit. This will result in a savings in maintenance manhours and eliminates the possibility of damage caused by soldering iron heat. Used in conjunction with any standard oscilloscope, the octopus affords a visual display of component condition.

The octopus, specifically designed to quickly test delicate components, does not deliver more than 1.0 milliampere of a-c; also, it energizes components during test, without removal of circuit interconnections much the same as they are energized in circuit during normal service.

While the octopus tests all components for shorts and opens, it can also be used to check front to back ratios on junction components (transistors and diodes). Moreover, utilizing Lissajous and combination patterns on the oscilloscope, the octopus easily analyzes integrated circuits and reactive components (capacitors and inductors) that defy ohmmeter analysis. It is useful also in checking circuit continuity (switches, fuses, lamps, printed wiring, etc.) and high-resistance solder joints.

As shown in figure 17-30, the few parts that go into the construction of the octopus are all common items. For this reason, and since all the parts are noncritical, they may be replaced by whatever suitable parts are locally available.

Low voltage and low current are necessary for protection of delicate components; the 1,000 ohm resistor placed across 1.0 volt assures the safe current of 1.0 milliampere. A center tapped 6.3 volt filament transformer (T1) is commonly used. It delivers about 3.0 volts a.c. (from center tap), which is dropped by resistors to 1.0 volt.

The leads should be color coded (black for the ground and red for the hot lead) and should be needle tipped or filed to a sharp point to penetrate the plastic and moisture-fungus-proof coating on some printed circuit boards. Dull leads usually fail to make proper contact. To prevent lead hunting, the leads should be permanently attached to the octopus. BNC connector jacks are used for the vertical and horizontal outputs or the cables may be permanently fastened.

A fuse, on/off switch, and indicating neon bulb may be added to the primary circuit if desired.

APPLICATION.—Since each basic component being tested projects a different display, the octopus operation is the utmost in simplicity. Figure 17-31 illustrates the most common displays on the oscilloscope.

When the tester is to be used, its vertical output is connected to the oscilloscope's vertical input and its horizontal output to the oscilloscope's horizontal input. The vertical and horizontal gain controls on the oscilloscope should be adjusted to prevent trace ends from going off the scope. Standard operational procedure for any board being tested for shorts requires that the power be removed. If the printed circuit board or chassis under test is

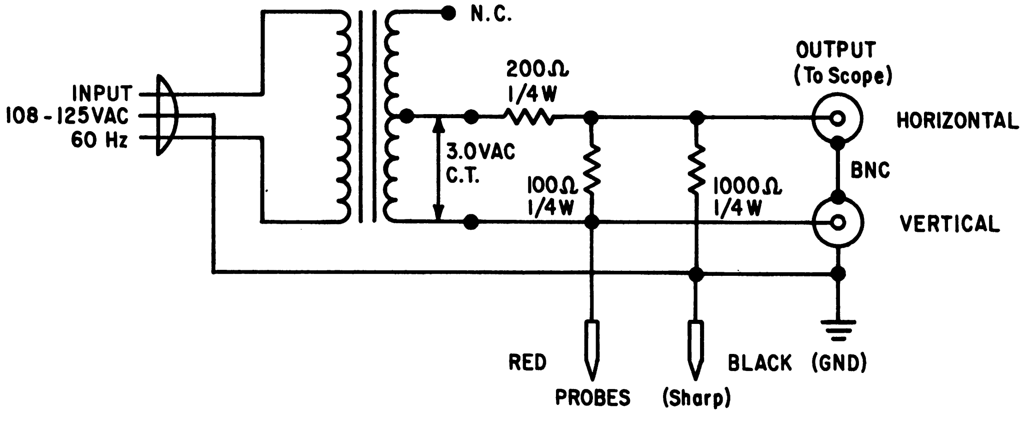


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Figure 17-30.—Octopus.

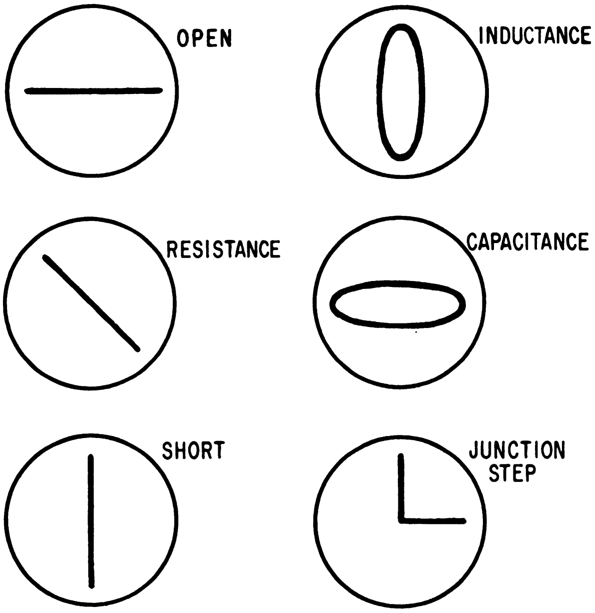

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Figure 17-31.—Typical oscilloscope displays.

grounded, the black lead should be attached to the ground end of the components.

Because the octopus is an a-c device, the technician is able to observe reactive components and Lissajous and front to back ratios of junction components. It is therefore unnecessary to reverse the leads. When observing transistors, check first from the base to one side and then from the base to the other side. A collector-to-emitter test would have to pass through two junctions in series and therefore usually does not produce a usable result. An ideal single junction check will produce a 90° step display, indicating a very high front-to-back ratio. This means an open in the reverse direction and a short in the forward direction. A display that is open more than 90° is something less than perfect. The wider the angle, the less the merit of the junction. Refer to figure 17-32.

For the technician to become proficient in testing components in circuit, it is only necessary for him to recognize the combination patterns arising from grouped components. If the diode and capacitor shown in figure 17-33 were under test, the display shown in that figure would be the result. The oscilloscope presents both a Lissajous (Xc reactance) and a 90° junction step, informing us that the components are neither shorted nor open.

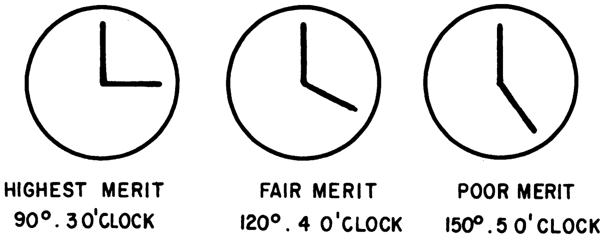

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Figure 17-32.—Transistor check, single junction.

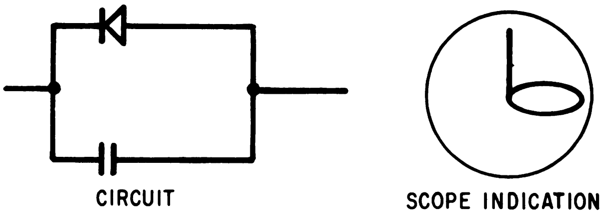

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Figure 17-33.—Diode check.

If the transistor circuit shown in figure 17-34 were under test (base to emitter), the trace shown would result. The scope pattern comprises

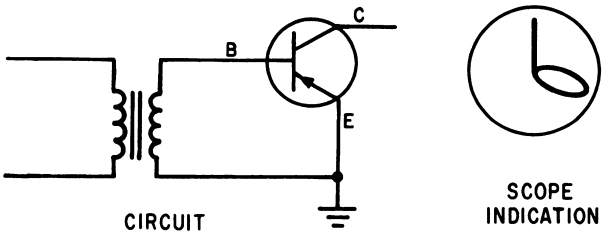

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Figure 17-34.—Transistor check, base to emitter.

both a junction step and a Lissajous, again informing us that the components are neither shorted nor open. Because of the coil resistance, the junction step appears to be greater than 90°, in fact, approximately 120°. This is common in any circuit that contains resistance in parallel with a junction component.

If the transistor in figure 17-35 contained an electrical short between the base and collector, the display shown would result during testing from the base to the collector.

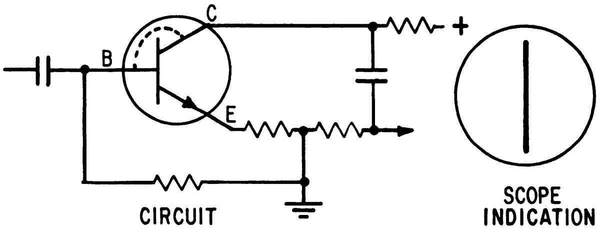

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Figure 17-35.—Transistor check, base to collector.

To check a potentiometer for noise, connect one probe to the pot arm and the other probe to either end, then manipulate the pot through its range while observing the oscilloscope pattern. Refer to figure 17-36.

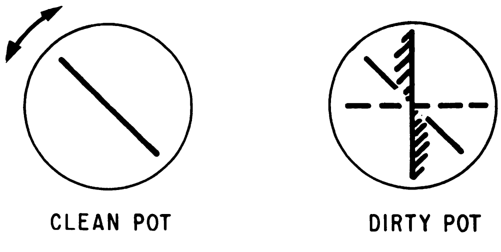

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Figure 17-36.—Potentiometer noise check.

To distinguish NPN from PNP transistors, move the red probe to the transistor base and the black lead to either the emitter or collector. If the step pattern opens downward, the transistor is NPN; if the pattern opens upward, the transistor is PNP. The same techniques can also be used to determine diode direction.

Occasionally it may appear necessary to desolder a part to determine its condition. It has been found that in such instances a comparison check with a known good board does away with the need to desolder the suspect component. This comparison method, which gives conclusive results, is recommended whenever there is any question regarding a component's operating condition.

Very small value capacitors will appear open rather than reactive, and very small inductors will appear shorted rather than reactive. In most cases, however, this is immaterial, since it is still possible to detect a shorted capacitor and any open inductors. Obviously an ohmmeter could do no better than the octopus on such components. There is, however, a method for regaining the active Lissajous for observation of these small components when that is desired; merely increase the gain adjustments on the oscilloscope to the desired amplification. Remember, of course, to return the gain settings to normal before checking other components.

TRANSISTOR CURVE TRACER (TEKTRONIX 575)

The Transistor Curve Tracer 575 is employed to plot or trace characteristic curves of transistors and other semiconductor devices. There are two different methods to plot the characteristic curves of a transistor. One is to apply d-c voltages and take measurements point-by-point. The other method is to use changing voltages and display the curve on an oscilloscope.

The 575 displays the curves by the use of the oscilloscope. There are several advantages in the use of the second method. To begin with, it is faster and more accurate than the point-by-point method. The point-by-point method may allow small irregularities in the characteristics to go undetected. Since heat is a major factor in transistor operation, errors caused by heat are reduced because the periods of applied power are shorter. Another definite advantage is that permanent records of the curves traced out on the oscilloscope may be easily produced at a reasonable cost by the use of photographic equipment.

This equipment is also provided with a self-calibration test. The operator can quickly reassure himself of the accuracy of the test set by the use of this built-in calibration check, in case a displayed curve deviates from the published nominal characteristic curve. The following paragraphs describe briefly how the 575 works and outlines a method for determining dial settings for transistors found in the fleet.

An illustration of the front panel of the equipment is shown in figure 17-37. As can be seen the controls are grouped into five blocks, with a test connector panel at the base of the test set. In addition to the block arrangement the panel is also color coded to simplify the operation. The collector currents and voltages are referenced by the sections of the panel etched in red; the sections etched in blue refer to the base currents and voltages. An exception to this color code is when a common base transistor configuration is being tested; at that time the blue is in reference to the emitter.

In the description of the five functional divisions that follows, refer to figure 17-37 for the item numbers listed; a functional block diagram is also given in figure 17-38.

The collector sweep circuit supplies the transistor under test with a collector voltage which is the output of a full-wave rectifier without any filtering. The 60-Hz line voltage is supplied to the full-wave rectifier and the output of the rectifier is 120-Hz pulses. The output waveform varies from zero volts to some peak value which can be controlled from the front panel (items 2 and 4). The peak voltage can be varied in two ranges, from 0 to 20 volts and from 0 to 200 volts. The polarity of the sweep voltage can be reversed in order to check both PNP- and NPN-type transistors (item 3). A variable amount of resistance can be placed between the collector sweep supply and the transistor under test in order to limit the maximum amount of collector dissipation (item 1).

Base Step Generator

The step generator develops currents and voltages which change value in stairstep fashion in synchronization with the collector sweep voltage (items 12, 16, 17, and 18). The output of the generator can be reversed in polarity and can be connected to either the base or the emitter of the transistor under test (item 13). The number of steps can be varied from 4 to 12 according to the type of display desired (item 14).

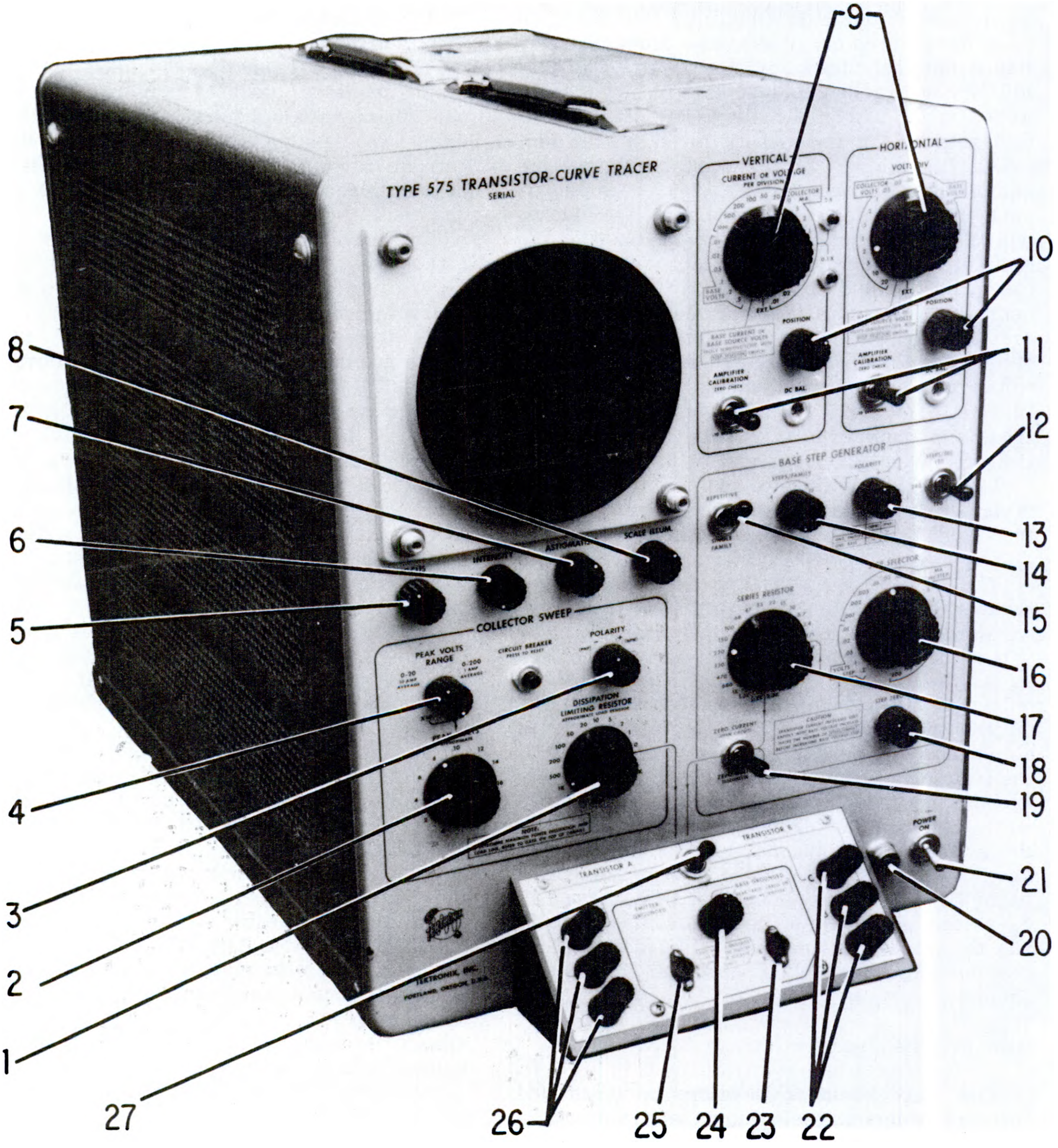
Display Function

The display function includes the three major functional blocks remaining; the vertical and horizontal amplifiers, and the cathode-ray tube. (A description of the operation of a cathode-ray tube is given in Basic Electronics; an oscilloscope is also discussed later in this chapter.)

The horizontal and vertical amplifiers of the cathode-ray tube display can be driven by several different inputs, depending upon what characteristics are of interest (item 9). The horizontal amplifier can select any of four inputs and display one of them on the horizontal axis. The four inputs are base volts, collector volts, base current or base-source volts, and external. In the base volts position, the horizontal amplifier is connected to the base of the transistor under test. In the collector volt position, the horizontal amplifier is connected to the collector of the transistor under test. Both of these inputs have several positions so that the scaling factor can be changed. The base-current or base-source volts position connects the output of the base step generator into the horizontal amplifier. The external position connects the horizontal amplifier to two coax connectors on the rear of the instrument.

The vertical amplifier can also select from four different inputs: collector MA, base volts, base current or base-source volts, and external. Base volts, base current or base-source volts, and external positions are the same as described for the horizontal amplifier, but in the collector MA position, the vertical axis will give a plot of collector current.

INTERPRETING THE DISPLAY.—As the collector voltage changes from zero to some peak value and back to zero again, the step generator output remains at some specific level and then changes to some new level for the next collector voltage cycle. The collector voltage is swept at a rate of 120 Hz, and the step generator changes steps or level after every cycle (in the 240 steps per second, the step generator changes at both the zero point of the collector sweep and at the maximum point). Figure 17-39 is a plot of collector sweep voltage and base step generator current. It should be noted that the collector sweep makes a complete excursion,



AT.144

Figure 17-37.—Transistor curve tracer (Tektronix 575).

Nomenclature for figure 17-37.

1. Dissipation limiting resistor.
2. Peak volts control.
3. Polarity switch.
4. Peak volts range.
5. Focus control.
6. Intensity control.
7. Astigmatism control.
8. Scale illumination.
9. Vertical/horizontal select.
10. Display position.
11. Amplifier calibration.
12. Steps/sec selector.
13. Polarity switch.
14. Steps/family.
15. Repetitive/single family.
16. Step selector.
17. Series resistor.
18. Step zero.
19. Zero current/voltage.
20. Indicator lamp.
21. Power ON-OFF.
22. Binding posts B.
23. Socket B.
24. Configuration switch.
25. Socket A.
26. Binding posts A.
27. Comparison switch.

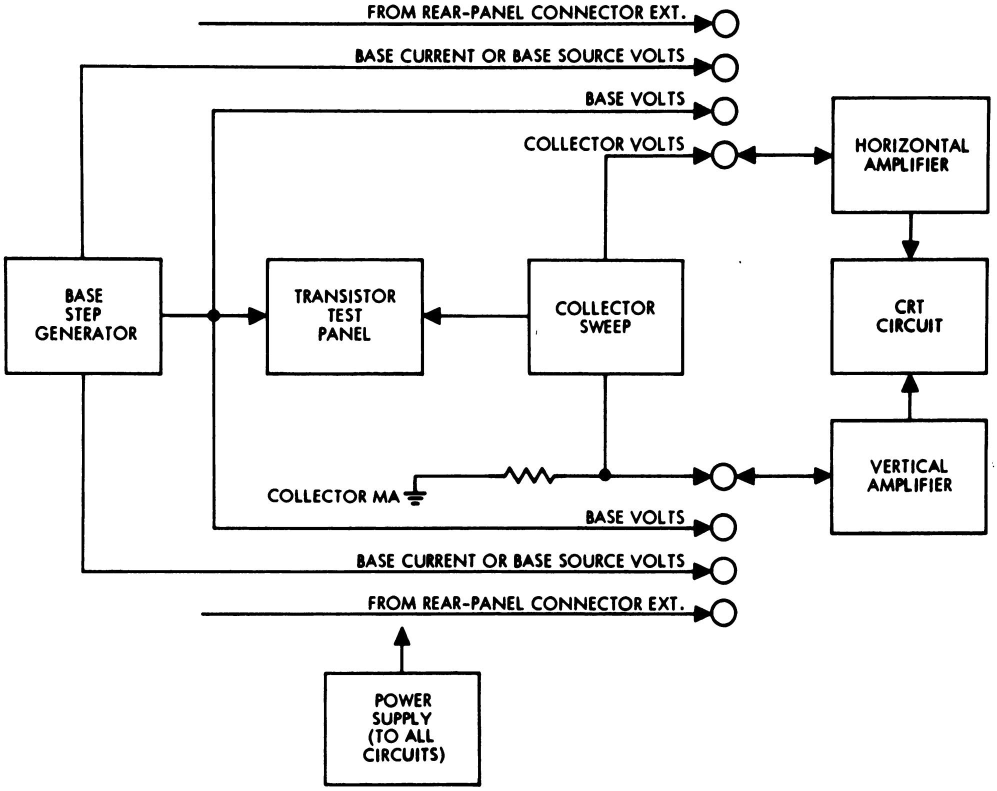

FROM REAR-PANEL CONNECTOR EXT.
BASE CURRENT OR BASE SOURCE VOLTS
BASE VOLTS
COLLECTOR VOLTS
HORIZONTAL AMPLIFIER
BASE STEP GENERATOR
TRANSISTOR TEST PANEL
COLLECTOR SWEEP
CRT CIRCUIT
COLLECTOR MA
VERTICAL AMPLIFIER
BASE VOLTS
BASE CURRENT OR BASE SOURCE VOLTS
FROM REAR-PANEL CONNECTOR EXT.
POWER SUPPLY (TO ALL CIRCUITS)

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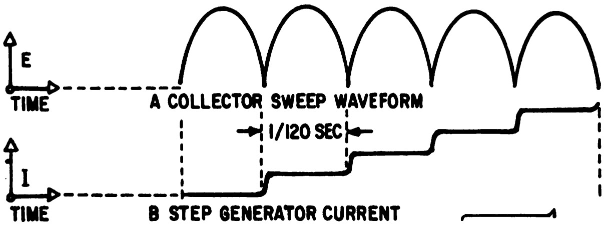
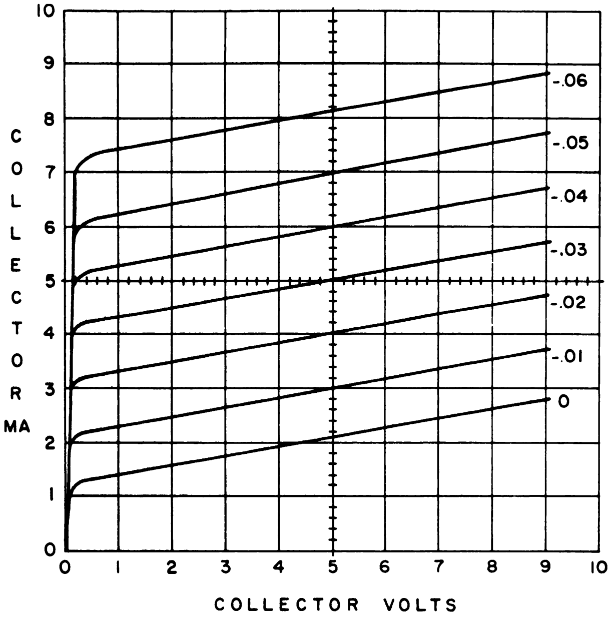
Figure 17-38.—Transistor curve tracer block diagram.



AT.116
Figure 17-39.—Waveforms of collector sweep versus step generator current.

while the base is at some steady value. As the next collector sweep starts, the base current is changed to the next value of current selected by the dials on the front of the instrument, and again the base current will remain steady while the collector voltage is varied.

As previously mentioned, the waveforms of figure 17-39 can be reversed by switches on the front panel in order to check either PNP or NPN.



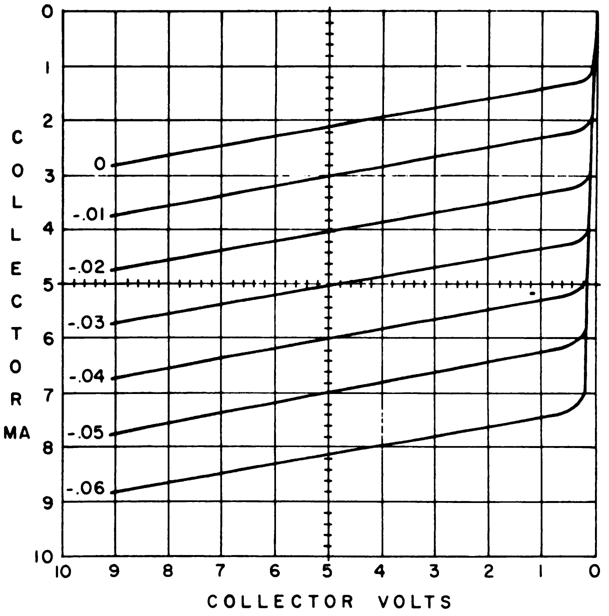
AT.117
Figure 17-40.—Typical NPN collector curves.

Figure 17-40 is a plot of collector voltage and collector current for given values of base current for an NPN transistor. For this type of transistor, it is a convention to have the lower left-hand corner represent zero collector voltage and current. In this graph, it was arbitrarily decided that each division to the right of the lower left-hand corner of the horizontal axis would represent a collector voltage change of one more volt positive. This would indicate a collector voltage swing of zero to 10 volts positive. The vertical axis is a plot of collector current varying from zero milliamperes in the lower left-hand corner to 10 milliamperes at the top of the graph in 1 milliampere steps. The different lines on the graph represent different values of base current; in this case, each line represents a change of 0.01 milliampere. If this graph had been for a PNP rather than for an NPN, the upper right-hand corner would have represented zero collector voltage and zero collector current. The divisions to the left would have represented negative collector voltage and the divisions downward from the top would have indicated the amount of negative current. This would have made the family of curves to appear as shown in figure 17-41.

These curves are known as the static collector characteristics for a common emitter configuration or output characteristics curve. Curves can be developed for common base and common collector also, but normally the information is available for the common emitter mode. Using this configuration, it is easier to check the transistor. To thoroughly describe how a transistor is going to work in a circuit, it is necessary to know the input characteristic curve as well as the output curve. The input characteristic curve is developed by plotting base current on the horizontal axis, base to emitter voltage (V_{RE}) on the vertical axis at different values of collector to emitter voltage (V_{CE}). Although it is necessary for the design engineer to know the input characteristic curve when designing a circuit, the output characteristic curve will normally give the maintenance technician enough information to allow him to evaluate a transistor.

Measuring Beta (h_{fe})

One means of measuring the quality of a transistor is the beta (β) or current gain in the



AT.118

Figure 17-41.—Typical PNP collector curves.

common emitter configuration. Mathematically, beta is represented by the formula

$$\beta = \frac{\Delta ic}{\Delta ib}$$

where V_{CE} is constant. Beta is also called the forward current transfer ratio and represented by the symbol h_{fe}, which is derived from the hybrid equivalent circuit of a transistor. To determine the beta from the output characteristics, measure the change in collector current between two values of base current at some constant collector voltage; for instance, in figure 17-40, to determine the beta at a collector voltage of 5 volts, measure the change in collector current between the base current curves of 0.02 ma and 0.03 ma. In this example, the change in collector current measures 1 ma, so the beta is equal to the change in collector current divided by the change in base current or

$$\frac{1 \times 10^{-3}}{0.01 \times 10^{-3}} = 100$$

Measuring I_{CO}

Another characteristic of a transistor is the I_{CO}, also called I_{CBO}. This is the collector current when the collector is biased in the reverse direction (high resistance, normal connection) with respect to the base, and the emitter is open-circuited. The I_{CO} of a transistor is highly temperature-dependent and the measurement made with the curve tracer will be at the ambient temperature only; but it is still significant. The method used to measure the I_{CO} is shown schematically in figure 17-42. Notice that the emitter is not connected.

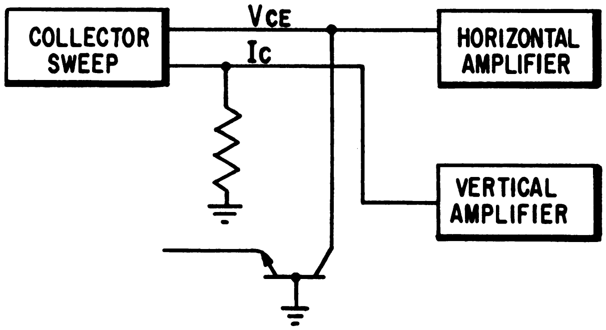


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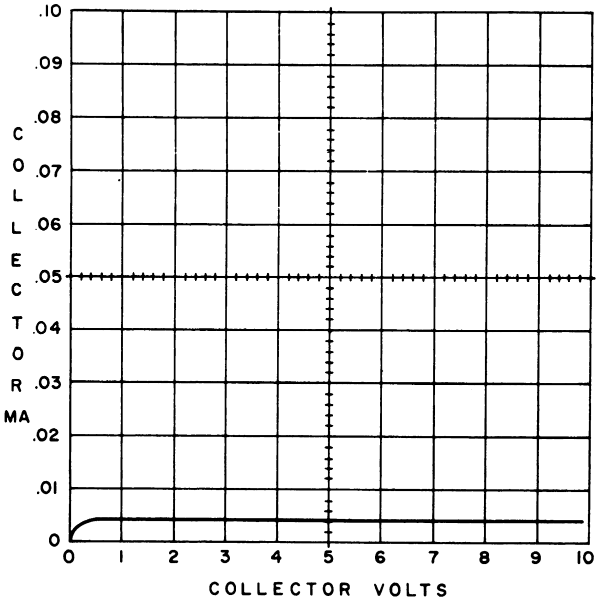
Figure 17-42.—Connections for checking $I_{CO}(I_{CBO})$.

The display of the curve tracer when measuring I_{CO} is shown in figure 17-43. The vertical axis indicates collector current, just as it did when beta was being measured; but now the vertical amplifier is adjusted to afford maximum gain so that the small amount of current causes a noticeable deflection. The horizontal axis is still calibrated to show collector voltage.

The technician must know the beta and I_{CO} of a transistor in order to tell whether or not the one he is testing is good. Since no manual describing the characteristics of different transistors is provided with the curve tracer, it is necessary to obtain this information from other sources. NavWeps 16-1-530 Replacement Guide, Semiconductor Device (Transistors and Semiconductor Diodes), dated May 1963, is an excellent source. For those transistors not listed in this publication, a specification sheet can be obtained from the manufacturer.



AT.120

Figure 17-43.—Typical display of $I_{CO}(I_{CBO})$

Section 1A of NavWeps 16-1-530 is a list of transistor replacements. Section 1A also gives the technical section in which a specific transistor is listed. These are Sections 2 through 10. To use this manual, look up the transistor in the technical section which applies; descriptions at the top of each page tell whether the transistor is germanium or silicon, PNP or NPN, low or high power. The important columns in the technical section needed to obtain information on testing are MAXIMUM COLLECTOR DISSIPATION, ABSOLUTE MAX RATINGS, MAX I_{CBO} at MAX V_{CB}, Typical "h" Parameters at 25°C.

Under the column labeled Typical "h" Parameters, there is listed a typical h_{fe} or a minimum and maximum value of h_{fe} depending on which technical section the transistor is listed in. In the same column is listed the collector voltage and collector current at which this h_{fe} is to be obtained.

The collector voltage (V_{CE}) and collector current (I_C) provide the starting points from which to determine the curve tracer settings; for instance, if the V_{CE} is 5 volts, the horizontal amplifier would be set to COLLECT or VOLTS, 1 volt per division. This would place the 5-volt position in the middle of the display, and if the I_C is 1-ma, the vertical amplifier would be set to COLLECT or MA, 0.2 MA per division. This would place the 1-ma position in the middle of the display. The collector sweep can be determined from these settings, since the horizontal amplifier is set to 1 volt per division. The collector voltage varies a total of 10 volts, so the PEAK VOLTS RANGE is in the 0 – 20 position and the PEAK VOLTS control is set at 10. To determine the setting for the DISSIPATION LIMITING RESISTOR, obtain the maximum collector dissipation from the column in the technical section labeled MAX COLL DISS. This, in conjunction with the setting of the PEAK VOLTS control, can be plotted on the chart on top of the curve tracer to obtain the correct setting of the limiting resistor.

The step generator is set up in the following manner. The switch labeled REPETITIVE-OFF-SINGLE FAMILY is set to REPETITIVE, and the control labeled STEPS/FAMILY is set counterclockwise. This gives four steps per family, which is usually sufficient; but if more are desired, set STEPS/FAMILY to any value. The switch labeled POLARITY has a chart under it showing the correct position for NPN and PNP. Use the portion of the chart pertaining to grounded emitter-type circuits. The switch labeled STEPS/SEC can be in either of the two 120 positions or in the 240. The only difference in the two 120 positions is that at one of them, the step generator changes level when the collector is at zero volts; and at the other position, the step generator changes level when the collector is at the maximum voltage. In the 240 position, the step generator changes level at both the zero collector voltage and at the maximum point. The step selector can be set by starting at the smallest change per step (0.001 ma) and increasing the size of the step until the display has the necessary separation between the values of base current to determine beta. In the alternative procedure, the beta listed in the technical section can be divided into the amount of collector current and the result used as the setting of the step selector. If there isn't enough separation between the lines representing the base current to accurately determine the beta, increase the amount of each base step until a good display is obtained.

To check the I_{CO} of the transistor, disconnect the emitter and change the current per division setting on the vertical amplifier to the most sensitive position (0.01 ma). Set the step zero very accurately, as described in NA 16-45-107, which is the Service Instruction Manual and Operating Instruction Manual for the curve tracer. After setting the step zero, note the difference between the step zero and the present position of the trace; this is an indication of the I_{CO}. The I_{CO} of the transistor is listed in the technical section, in the column MAX I_{CBO} at MAX V_{CB}, which describes the I_{CO} at BV_{CBO}—the breakdown voltage, collector-to-base with emitter open.

By measuring beta (h_{fe}) and I_{CO}(I_{CBO}), a fair picture of the condition of a transistor is presented. There is one thing that should be mentioned in connection with the curve tracer, however; matching of transistors. Some Navy equipments have matched pairs of transistors, but unless the specifications are checked, it cannot be automatically assumed that betas of the transistors are matched. Sometimes the betas are matched, sometimes they are not; many times several characteristics are matched.

SIGNAL GENERATORS

In the maintenance of airborne electronic equipment, it is often necessary to employ standard sources of RF energy. These energy sources are called signal generators.

The principal function of the signal generator is the production of an alternating voltage of the desired frequency and amplitude. The generated signal may be modulated or unmodulated, depending on the test or measurement in question.

When using the signal generator, the output signal is coupled into the circuit being tested and its progress through the equipment is traced by the use of some high-impedance device such as a vacuum tube voltmeter or an oscilloscope.

RF SIGNAL GENERATOR

Radiofrequency signal generators comprise a rather large and very useful class of test equipments. Because of the extremely wide frequency range in the RF region of the spectrum, many signal generators with different RF ranges, as well as other instrument refinements are available. The following general analysis of RF signal generators is provided to acquaint the technician with the principal circuits used in these generators.

In addition to the required power supply, the circuits common to most RF signal generators are the oscillator circuit, modulator circuit, and the output circuit.

The oscillator circuit has as its function the emission of a signal, the frequency of which can be accurately set to any point in the designed frequency range. The type of oscillator used depends on the range of frequencies required. It may have as its resonant circuit a simple coil and capacitor (LC), a tuned line, a tuned cavity, or any of the various specialized types designed for microwave frequencies.

The modulating circuit functions to change the RF output in accordance with the successive instantaneous voltage values of the modulating signal. For a particular generator the modulating signal may be provided by an internal source, an external source, or by both, depending upon the design of the instrument. A meter is often included to indicate (and to permit control of) the percentage of modulation. The form the modulating signal may take depends upon the application of the particular signal generator. It may be a sine wave, a square wave, or a pulse. Some instruments have special provisions for pulse modulation, which permits the RF signal to be pulsed over a wide range of pulse repetition frequencies (PRF) and at various pulse widths.

Usually the output circuit of the generator contains a calibrated attenuator and often an output level meter. The output level meter gives an indication of, and permits control of, the output voltage of the generator. The attenuator selects the amount of this output, and is often calibrated in microvolts.

Frequency-Modulated RF Signal Generators

Various types of frequency-modulated (FM) signal generators are available to the technician; however many of these are restricted to specialized applications. One exception is the type known as the sweep generator. The following general analysis of FM generators is given to provide basic information applicable to most types of FM generators. Sweep generators are discussed separately.

An FM signal is one in which the output frequency varies above and below a center frequency. The overall frequency variation is known as the frequency swing (or deviation), and the rate at which this swing recurs is controllable at any audio (or video) frequency rate for which the generator has been designed. The frequency change of the output may be accomplished by the mechanical variation of either the capacitance or inductance of the oscillator circuit, or the use of a reactance tube connected to the oscillator circuit. In the latter case, changes of the voltage impressed on the grid of the reactance tube change the amount of reactance introduced into the oscillator tuned circuit, and as a result cause the output frequency to change. The frequency of the signal on the grid of the reactance tube thereby controls the rate of frequency deviation, and the amplitude of the signal voltage controls the amount of the deviation.

SWEEP GENERATORS.—A sweep generator is a form of an FM signal generator, the carrier deviation of which is adjustable by means of a sweep-width control. The sweep generator differs from the ordinary FM signal generator in that the rate of carrier deviation is generally maintained at a fixed frequency. The voltage used to effect the deviation may be either a sine wave (very common) or a sawtooth waveform. Since an oscilloscope is used to observe the patterns which are formed when the passband of interest is swept by this type of generator, the oscilloscope time base must utilize (or be synchronized with) the same waveform used to produce the deviation. The horizontal (or time) axis of the pattern then represents the instantaneous frequency of the generator output, while the vertical axis shows the response characteristic of the circuit under test for each frequency. Sweep generators are widely used for the observation of response characteristics and the visual alinement of tuned circuits. The sweep generator is useful in checking the bandwidth of IF amplifiers used in radar receivers.

Deviation of the carrier may be accomplished either electromechanically or electronically. The electromechanical method consists of mechanically varying the capacitance or the inductance of the oscillator tank circuit, causing the frequency to vary accordingly. The electronic method makes use of a reactance-tube modulator.

A sweep generator produces patterns containing a considerable number of instantaneous frequencies. It is necessary to introduce marker signals, which are superimposed on the trace, in order to orient passband characteristics (or center frequency) of the circuit under test with respect to frequency. The circuit which produces the marker signals may be an integral part of the instrument, or the marker signals may be supplied from an external source.

Most modern frequency-swept signal generators use a reactance-tube method of modulation, since this results in greater flexibility and the equipment is lighter and more compact than would be possible with the rotating capacitor.

The reactance tube and its associated components are connected across the tank circuit of the oscillator in the signal generator. In many cases the a-c power line, which provides an excellent oscilloscope synchronizing medium, is coupled to the grid of the reactance tube to control the rate of the sweep. (Oscilloscopes are discussed later in this chapter.) The reactance-tube modulator has an advantage over electromechanical modulators in the respect that it can be excited by an external variable AF signal generator, whereas the electromechanical modulator is usually limited to single-frequency operations.

Pulse-Modulated RF Signal Generators

A pulse-modulated (PM) signal generator is similar to the conventional RF signal generator with the exception that its output consists of RF energy in the form of pulses which occur at an audio rate. Controls are provided to vary the pulse width (duration of each pulse) and the repetition rate (number of pulses per second). A common application of a pulse-modulated generator is found in the checking of receiver performance of many radar systems, which employ a pulse type emission.

Pulse-modulated RF signals are produced by generating a constant RF carrier by means of a conventional oscillator circuit and feeding this energy to the grid of a mixer stage which has at the same time impressed on its suppressor grid a square wave generated in a separate circuit. The positive half-cycles of the square wave allow the mixer tube to conduct, and the negative half-cycles cut the tube off. During the conducting intervals, the plate current is varied by the RF signal on the control grid. Therefore, pulses of RF current, corresponding to the positive half-cycles of the square wave, appear in the mixer plate circuit. The pulses are generally fed to one or more amplifier stages. Pulse time and repetition rate are varied by controls in the square wave circuit.

The Model 628A SHF signal generator (fig. 17-44) is a general purpose broadband signal generator which produces RF output voltages from 15 GHz to 21 GHz. A single control determines the output frequency which is directly read on a dial calibrated to an accuracy of 1 percent or better.

The 628A signal generator is provided with versatile modulation characteristics. The output can be frequency modulated, square wave modulated, or pulse modulated by internally or externally generated signals. It also provides synchronizing pulses for external equipment being used.

The 628A signal generator, in addition to producing an accurate and controllable radio-frequency test signal, can be used for the following:

1. Testing pulse systems.
2. Measuring sensitivity and selectivity of amplifiers, receivers, and other tuned systems.
3. Measuring signal-to-noise ratio of RF signals.
4. Making slotted line measurements.

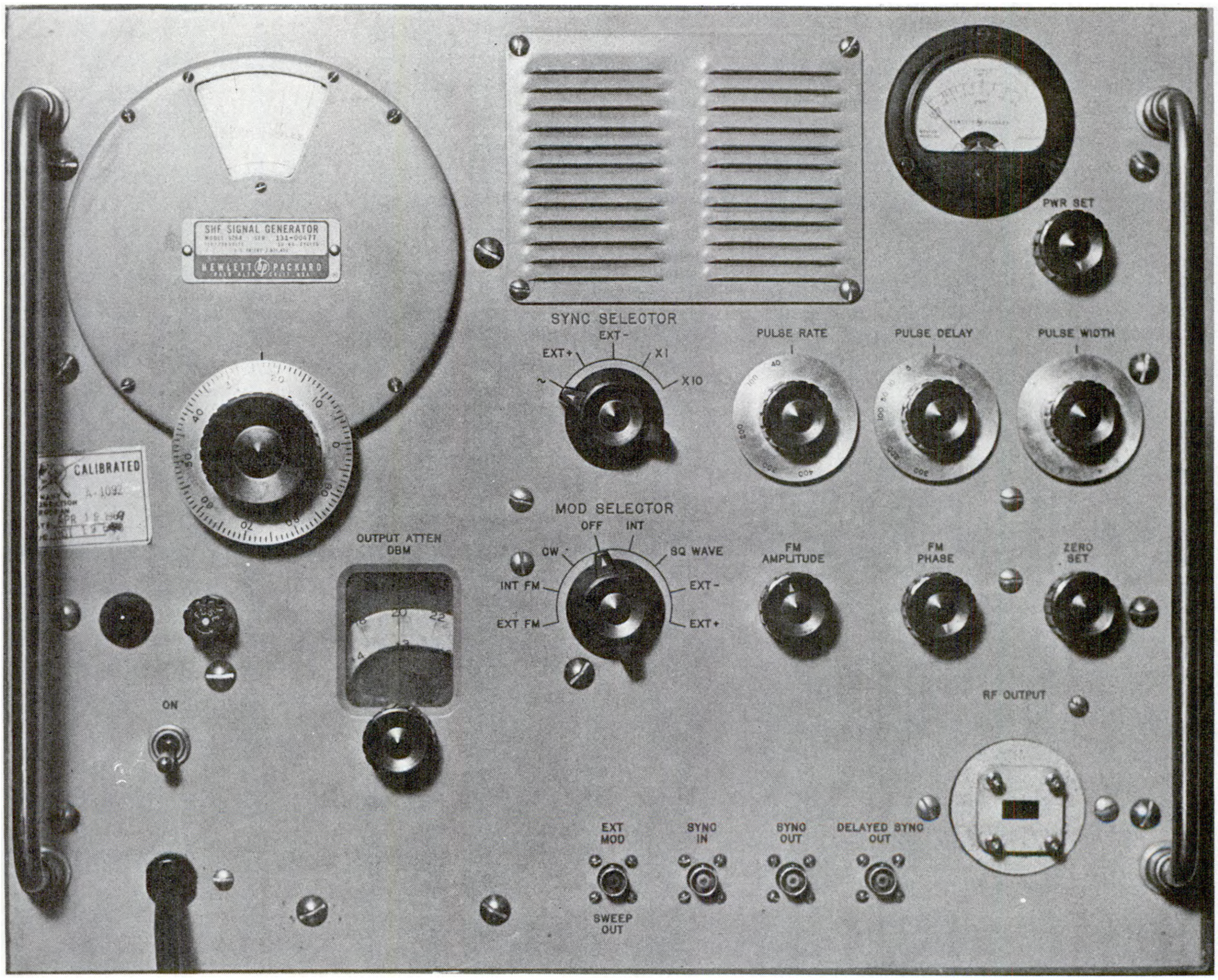


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Figure 17-44.—Model 628A SHF signal generator.

5. Investigation of microwave impedances and other transmission line characteristics.
6. Measuring frequency response of microwave systems.
7. Determining resonant frequency and Q of waveguide cavities.

Operating Procedure

The operation of the 628A signal generator consists of adjusting two major sections—the RF section and the modulator section. The RF section is adjusted first since this adjustment establishes the output power reference level for the output attenuators.

Figure 17-45 displays the front panel controls and connectors used in the operation of the 628A signal generator. A brief description of the function or operation of the front panel controls and connectors follows:

1. Supplies line power to the instrument.
2. OUTPUT ATTEN control—determines the RF output level from +10 dbm to -90 dbm (10 mw to 1 μμw).
3. MOD SELECTOR switch—used to select the desired type of modulation to be applied to the RF output signal.
4. EXT MOD/SWEEP OUT—used as an input for external modulation signals when MOD SELECTOR is set to EXT FM, EXT−, or EXT+; used as an output for a sweep signal which occurs only when MOD SELECTOR is set to INT FM.
5. SYNC IN connector—input for sync pulses. These pulses are used only when MOD SELECTOR is set to INT and SYNC SELECTOR to EXT−, EXT+, or ∿.
6. SYNC OUT connector—output for sync pulses in either square wave or pulse operation.
7. DELAYED SYNC OUT connector—output for delayed sync pulses in either square wave or pulse operation. These pulses are controlled by PULSE DELAY.
8. RF OUTPUT—N band type WR-51 waveguide, cover type flange.
9. FM AMPLITUDE control—determines the frequency deviation of the output signal when internal or external frequency modulation is employed.
10. FM PHASE control—determines the phase of frequency modulation from approximately +90° to -90° with respect to the SWEEP OUT signal only when internal frequency modulation is employed.
11. ZERO SET control—used to zero-set the power-monitor meter.
12. PULSE DELAY control—adjusts the time delay between the leading edge of the SYNC OUT pulse and the RF output pulse from 3 to 300 microseconds when the MOD SELECTOR is set to INT.
13. PULSE WIDTH control—adjusts the width of the RF output pulse from 0.5 to 10 microseconds when the MOD SELECTOR is set to INT.
14. PULSE RATE control—adjusts the repetition rate of the RF output pulse or square wave when the MOD SELECTOR is set to INT or SQ WAVE. The X1 or X10 position of the SYNC SELECTOR selects the multiplying factor to be applied to the reading of the calibrated PULSE RATE dial.
15. PWR SET control—used to establish the correct power level fed to the output attenuators.
16. SYNC SELECTOR switch—selects the type of synchronization to be employed by the signal generator during internal pulse modulation of the RF output signal.
17. Frequency control—used to set the desired RF output frequency. Frequency dial is read directly in kilomegahertz (GHz).

After turning the instrument on, allow at least 5 minutes for it to reach a stable operating temperature. If the ambient temperature is below 50°F, a longer warmup period is necessary. NOTE: The klystron tube contained in this instrument is expensive and has a shorter life than that of most conventional vacuum tubes. Filament and plate voltages remain on the klystron tube when the MOD SELECTOR switch is in the OFF position; therefore, power should be removed from the instrument when it is not in use in order to increase the useful life of the tube. Figure 17-45 indicates by number the turn-on procedure and CW operation. Turn-on procedure and CW operation is as follows:

1. Switch (1) to ON and allow at least a 5-minute warmup.
2. Set frequency dial (17) for desired frequency.
3. Set MOD SELECTOR (3) to OFF.
4. Adjust ZERO SET (11) to obtain a power-monitor meter indication exactly on ZERO SET index.
5. Set MOD SELECTOR (3) to CW.
6. Adjust PWR SET (15) to obtain a meter indication exactly on POWER SET index (red line at center of scale).

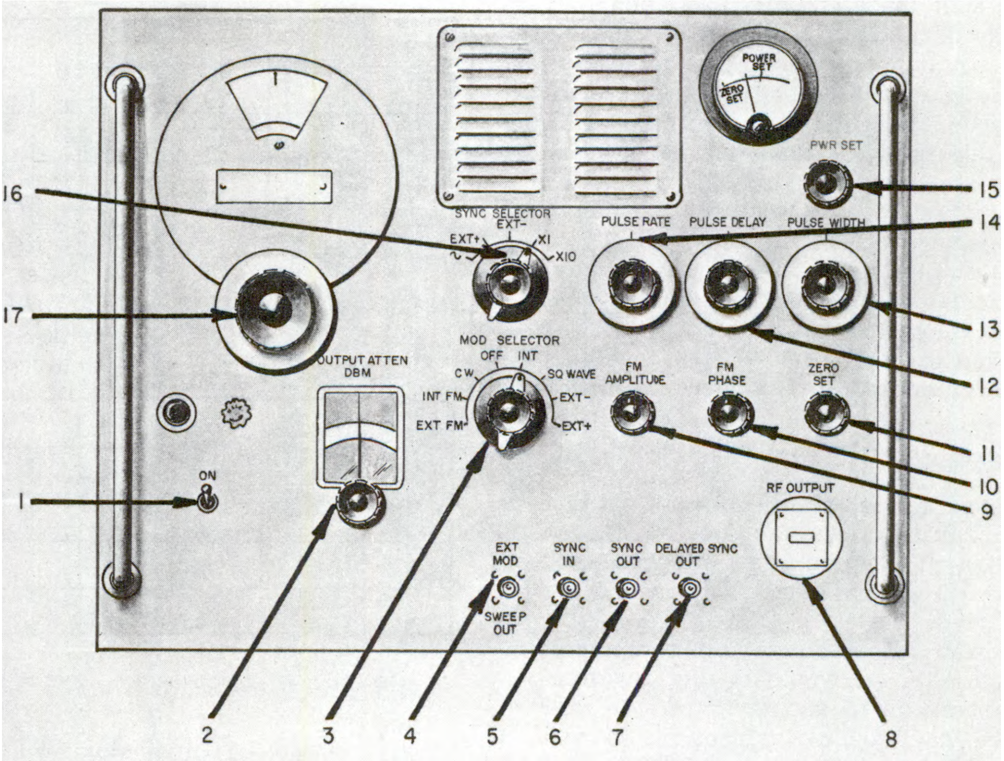

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Figure 17-45.—Model 628A SHF signal generator front panel controls and connectors.

7. Set OUTPUT ATTEN (2) for desired CW output level.

SIGNAL ANALYZERS

Signal analyzers, while used in many different situations, generally aid in the accomplishment of only one function, that is to check the response of an equipment under simulated conditions of specific operations.

WAVEFORM MEASUREMENT

Waveform measurements can be made by observing displays of voltage and current variations with respect to time, or by harmonic analysis of complex signals. Waveform displays are particularly valuable for adjusting and testing pulse generator, pulse former, and pulse amplifier circuits. The waveform visual display is also useful for determining signal distortion, phase shift, modulation factor, frequency, and peak-to-peak voltage.

The cathode-ray oscilloscope is commonly used for the analysis of waveforms generated by electronic equipment. Several types of cathode-ray oscilloscopes are available for making waveform measurements. The oscilloscope required for a particular test is determined by characteristics such as the input frequency response, the input impedance, the sensitivity, the sweep rate, and the methods of sweep control. The synchroscope is an adaptation of the cathode-ray oscilloscope which features a wideband amplifier, triggered sweep, and retrace blanking circuits which are desirable for the analysis of pulse waveforms.

Oscilloscopes are also incorporated in some harmonic analysis test equipment to display harmonic energy levels on a cathode-ray tube. To effectively analyze waveform displays, the correct waveshape must be known beforehand.

This information can be obtained from technical manuals for the equipment or from previous measurements of the same circuits when they are operating correctly.

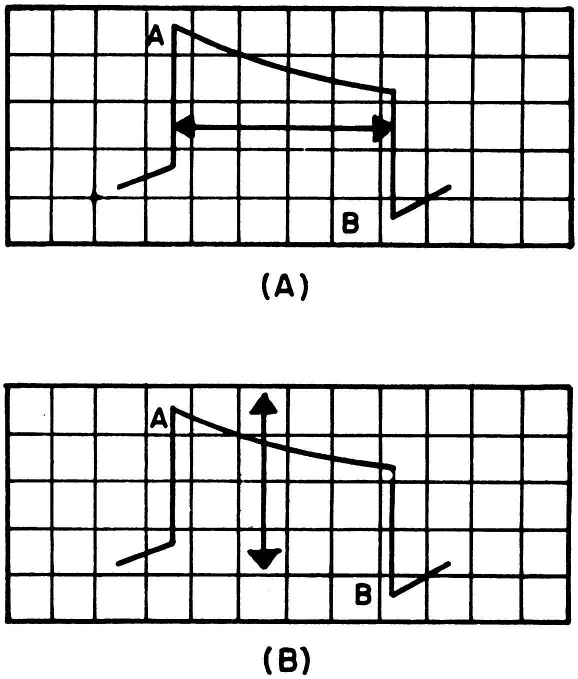
Harmonic analysis test sets can be used to determine the energy distribution in electrical signals. Frequency-selective circuits separate the signals into narrow frequency bands, and the energy in each band is indicated by a meter or displayed on a cathode-ray tube. A group of frequency-selective circuits can be connected in parallel, a single frequency-selective circuit can be tuned manually or automatically, or a heterodyne method (using a sweep generator and fixed-tuned circuit) can be used to select electrical power present in a narrow frequency band.

OSCILLOSCOPE

An oscilloscope is an electronic test set that displays information on the face of its cathode-ray tube (CRT). It is sometimes referred to as an "O" scope. The uses of an oscilloscope are many and varied, but it is used primarily to troubleshoot and aline electronic equipment; which is accomplished by observing and analyzing waveforms as to shape, amplitude, and duration. The Maintenance Instructions Manual for the particular equipment on which work is being performed will designate what waveforms are to be observed at the various test points throughout the equipment. Waveforms that will be observed at any one selected test point will differ, depending on whether the operation of the equipment is normal or abnormal.

The display observed on a cathode-ray oscilloscope is ordinarily one such as shown in figure 17-46. This illustration shows the instantaneous voltage of the wave plotted against time. Elapsed time is indicated by horizontal distance, from left to right, across the etched grid (graph) placed over the face of the tube. The amplitude of the wave is measured vertically on the graph.

The oscilloscope is also used to picture changes in quantities other than simply the voltages in electric circuits. If an electric current waveform is of interest, it is usually satisfactory to send the current through a small series resistor and look at the voltage wave across the resistor with the oscilloscope. Other quantities such as temperatures, pressures, speeds, and accelerations can be translated into voltages by means of suitable transducers, and then viewed on the oscilloscope.



(A)

(B)

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Figure 17-46.—Typical waveform display. (A) Measurement of elapsed time; (B) measurement of voltage difference.

Interpreting the Display

To find the elapsed time between two points on the graph (fig. 17-46 (A)) such as A and B, multiply the horizontal distance between these points in major graduated divisions by the setting of the TIME/DIV (time per division) control. This control sets the horizontal sweep rate of the oscilloscope. The distance between points A and B is 4.8 major divisions. If the TIME/DIV control is set at 100 microseconds per division, then the elapsed time between points A and B must be 4.8 x 100 = 480 microseconds. In general, elapsed time = horizontal distance in divisions X TIME/DIV setting.

If a MULTIPLIER control is associated with the TIME/DIV control, multiply the above result by the setting of the MULTIPLIER. If a MAGNIFIER is in operation, divide the result by the amount of magnification.

To find the voltage (fig. 17-46 (B)) difference between any two points on the graph, such as A and B, multiply the vertical distance between these points in major graduated divisions by the setting of the VOLTS/DIV control. This control sets the vertical deflection factor or sensitivity of the oscilloscope. The vertical distance between points A and B is 4.0 divisions: If the VOLTS/DIV control is set at 0.5 volts per division, then the voltage difference between points A and B must be 4.0 x 0.5 = 2.0 volts.

The quantity called pulse repetition rate (or pulse repetition frequency) for periodic pulses can be expressed as the number of pulses per unit of time. Examples: 10 pulses per second and 50 pulses per microsecond.

In using the oscilloscope to measure the frequency or repetition rate of periodic waveforms, first read the horizontal distance in major divisions between corresponding points on two succeeding waves. This is the horizontal distance occupied by one cycle of the wave. Multiply this by the setting of the TIME/DIV control in seconds, milliseconds, or microseconds. Take the reciprocal of this product; that is, divide it into 1. The result is the desired frequency or repetition rate.

It is convenient to use square waves, rather than other forms of waves, for testing of equipment because the nature of a defect, rather than simply its presence, is suggested by the kind of distortion which occurs to a square wave. By observing the square wave response, it is easy to tell whether the transmission of low or high frequencies is affected. This observation is not so well separated with regard to frequency if waves other than square waves are used.

If two linear devices give identical responses when square waves are fed into them, they can, in general, be expected to give responses similar to each other when other waveforms are fed into them.

Information Contained in a Square Wave

It can be shown that a periodic wave contains the following components: (1) a fundamental wave, which is a sine wave having a frequency equal to the repetition frequency of the square wave, and (2) an infinite series of harmonics—sine waves having frequencies which are equal to whole numbers multiplied by the fundamental frequency. The harmonics must be properly related in phase and in amplitude to the fundamental

Waveform D of figure 17-47 depicts a periodic rectangular wave (square wave). In the case of the square wave, the only harmonics present are the "odd" harmonics (those whose frequencies are equal to the fundamental frequency multiplied by odd whole numbers); and the strengths of the harmonics vary in inverse proportion to the frequencies of the harmonics, the fifth harmonic being one-fifth as strong as the fundamental, for example. The way in which these waves combine to make up a square wave is suggested by figure 17-47.

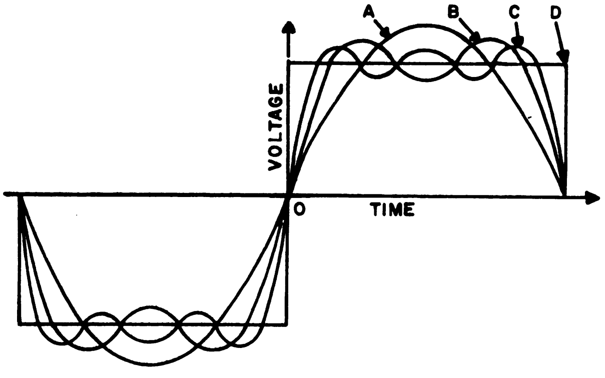

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Figure 17-47.—Addition of harmonics to fundamental waveform.

The four curves shown in figure 17-47 illustrate the following:

1. Curve A the fundamental sine wave.
2. Curve B the sum of the fundamental and third harmonic.
3. Curve C the sum of the fundamental plus third and fifth harmonics.
4. Waveform D is the ultimate square wave.

It will be noted that the first few harmonics combine with the fundamental to provide an approach to an actual square wave. Additional harmonics, of higher frequencies, would cause the leading edge of the wave to rise more rapidly, and produce a sharper corner between the leading edge and the top of the wave. It would require an "infinite" range of harmonics to produce a truly vertical leading edge and an actual sharp corner, and this situation is physically impossible to produce. But waves can be generated which are very close to this ideal situation. (The same considerations apply to the falling edge of the waveform, and the following corner.)

Information regarding the amplitude and phase relationships of the higher harmonics is, then, contained in the leading-edge steepness and in the sharpness of the corner.

If low frequency components (fundamental and the first few harmonics) are not present in the proper amounts and in the correct phase relationships, the part of the square wave affected will be the flat top. Figure 17-48 (A) shows the location of the low and high frequency information in a square wave. Low frequency defects will appear in the form of slope or general curvature in the top, as shown in (B) and (C) of the figure. In (B) of the figure, the low frequency components have leading phase angles and are attenuated. In (C) the low frequency components have lagging phase angles and are accentuated.

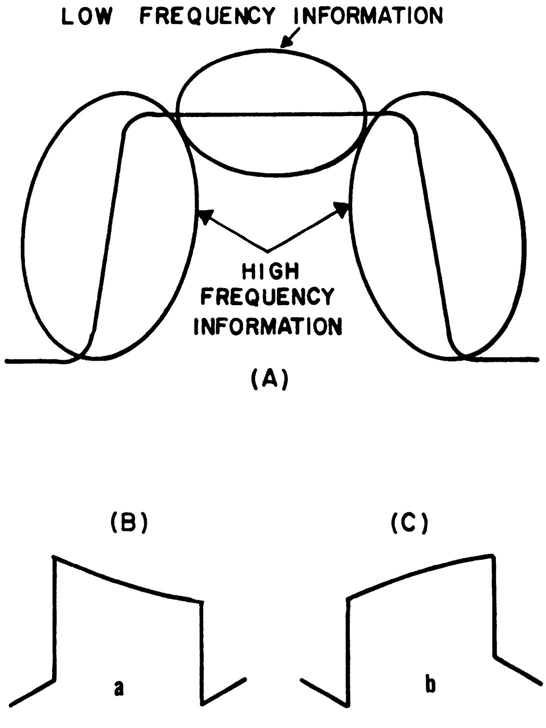

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Figure 17-48.—Information found in a square wave.

Oscilloscope Block Diagram

Figure 17-49 is a block diagram of a typical oscilloscope, omitting power supplies. The waveform (A) to be observed is fed into the vertical amplifier input. The calibrated VOLTS/DIV control sets the gain of this amplifier. The push-pull output (B and C) of the vertical amplifier is fed through a delay line to the vertical deflection plates of the cathode-ray tube.

The time base generator or "sweep generator" develops a sawtooth wave (E) that is used as a horizontal deflection voltage. The rising or positive-going part of this sawtooth, called the "runup" portion of the wave, is linear. That is, it rises through a given number of volts during each unit of time. This rate of rise is set by the calibrated TIME/DIV control. The sawtooth voltage is fed to the time base amplifier. This amplifier supplies two output sawtooth waveforms (G and J) simultaneously—one of them positive-going, like the input, and the other negative-going. The positive-going sawtooth is applied to the right-hand horizontal deflection plate of the cathode-ray tube, and the negative-going sawtooth is applied to the left-hand deflection plate. As a result, the cathode-ray beam is swept horizontally to the right through a given number of graduated divisions during each unit of time, the sweep rate being controlled by the TIME/DIV CONTROL.

In order to maintain a stable display on the cathode-ray tube screen, each horizontal sweep must start at the same point on the waveform being displayed. To accomplish this, a sample of the displayed waveform is fed to a "trigger" circuit which gives a negative output voltage spike (D) at some selected point on the displayed waveform. This triggering spike is used to start the rising portion of the time base sawtooth. As far as the display is concerned, then, "triggering" can be taken as synonymous with the starting of the horizontal sweep of the trace at the left-hand side of the grid.

The rectangular "unblanking" wave (F) derived from the time base generator is applied to the grid of the cathode-ray tube. The duration of the positive part of this rectangular wave corresponds with the duration of the positive-going or rising part of the time base output, so that the beam is switched on during its left-to-right travel and is switched off during its right-to-left retrace.

In many cases the leading edge of the waveform being displayed is used to actuate the

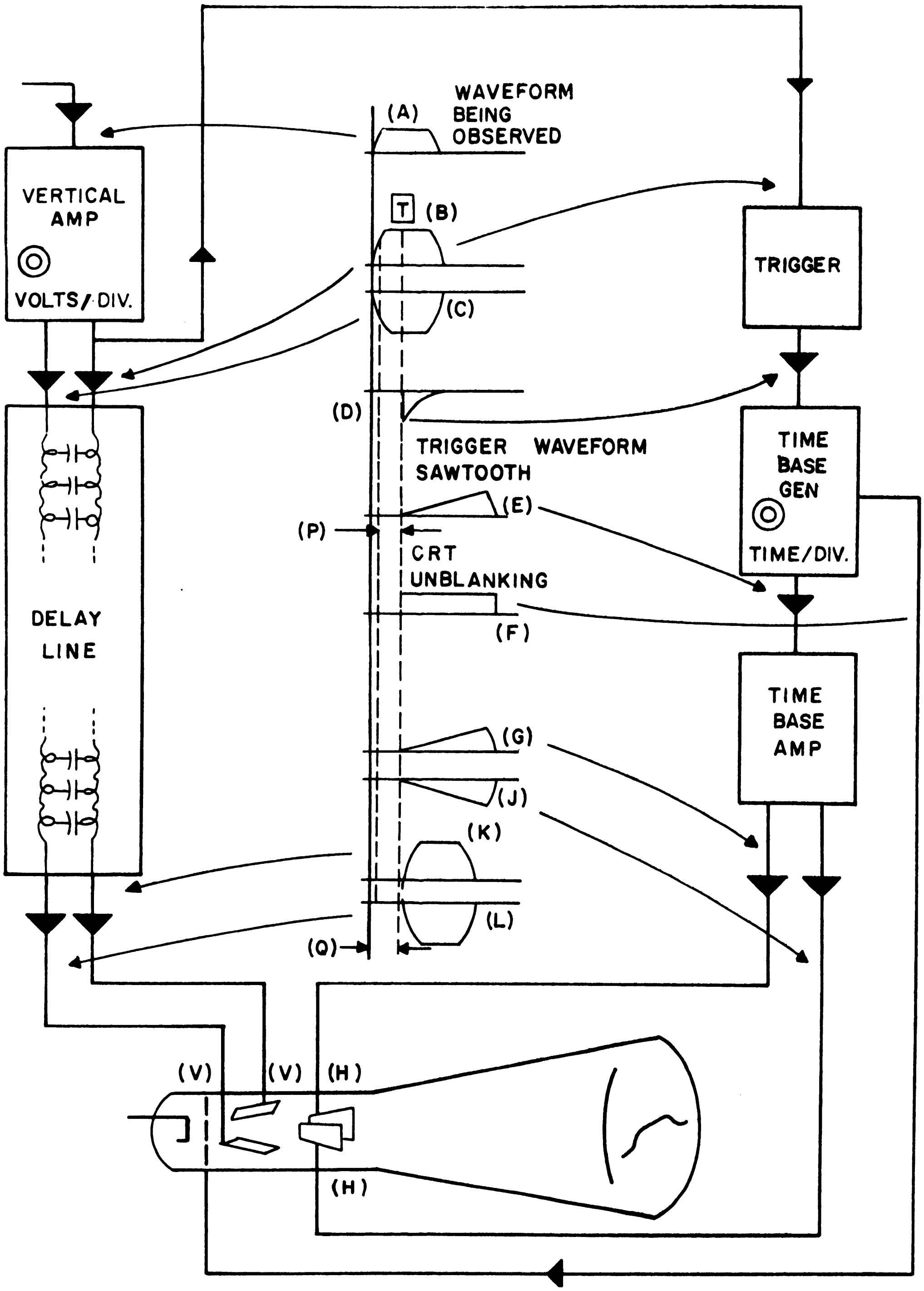

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Figure 17-49.—Typical oscilloscope block diagram.

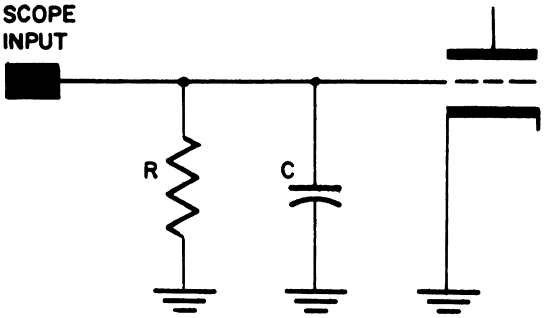
trigger circuit. Yet it may be desirable to observe this leading edge on the screen—and the triggering and unblanking operations require a measurable time (P), often about 0.15 microsecond. To permit the leading edge to be seen, a delay (Q) of about 0.25 microsecond is introduced by the delay line in the vertical deflection channel after the point where the sample of the vertical signal is tapped off and fed to the trigger circuit.

The purpose of the delay line is to retard the application of the observed waveform to the vertical deflection plates until the trigger and time base circuits have had an opportunity to begin the unblanking and horizontal-sweep operations. This permits viewing the entire desired waveform—even though the leading edge of that waveform was used to trigger the horizontal sweep.

If the delay line were not used, only that portion of the waveform following the instant (T) in waveform (A) could be seen.

Oscilloscope Probe

The input circuit to the vertical amplifier of an oscilloscope can be simulated by a high resistance R shunted by a small shunt capacitance C, as shown in figure 17-50.



AT.127

Figure 17-50.—Oscillator vertical amplifier input circuit.

In some applications, even this high resistance and small capacitance can produce undesirable loading upon the circuit whose waveforms are being examined by means of the oscilloscope. This loading can cause the oscilloscope presentations to be different from the waveforms that would be present with the oscilloscope disconnected. One use of a passive probe is to reduce this resistive-capacitive loading on the circuit under investigation.

The probe includes a resistor R_p shunted by a capacitor C_p (fig. 17-51). This combination is connected in series with the inner conductor of the cable to the oscilloscope input. The result is that, when the probe is connected to the circuit under investigation, there is connected to that circuit a new effective loading capacitance smaller than the original capacitance C and a new effective loading resistance larger than the original resistance R. Thus the loading effect of the oscilloscope input-circuit on the circuit under investigation is reduced through the use of the probe.

A second effect of the probe is to reduce the amount of signal voltage applied directly to the oscilloscope input connection for a given amount of original signal voltage. This occurs because of the voltage-divider action of R_p and R. This effect is taken into account in the "attenuation ratio" marked on the probe. Thus if the probe is marked "10X ATTEN" all oscilloscope voltage indications must be multiplied by 10.

If an oscilloscope equipped with a probe is used to look at a square wave, and the probe capacitor C_p is too small, some of the high frequency components of the square wave will be bypassed around the oscilloscope input terminals by the input capacitance C. Thus the steepness of the leading edge of the displayed square wave is reduced. (See fig. 17-52 (A).)

If the probe capacitor is adjusted to the correct value, a compensating amount of high frequency information is bypassed around the probe resistor R_p to make up for the loss through C, and the leading edge of the displayed square wave will be restored to its original steepness (B). If C_p is made too large, the high frequency response of the circuit will be overcompensated and apply too much high frequency information to the oscilloscope input connection. This results in an overshoot in the displayed waveform that was not present in the original (C). C_p can be adjusted to its correct value by using the probe to display the square wave generated by the voltage calibrator that is a part of the oscilloscope. Adjustment is made to display a square wave with as flat a top as possible.

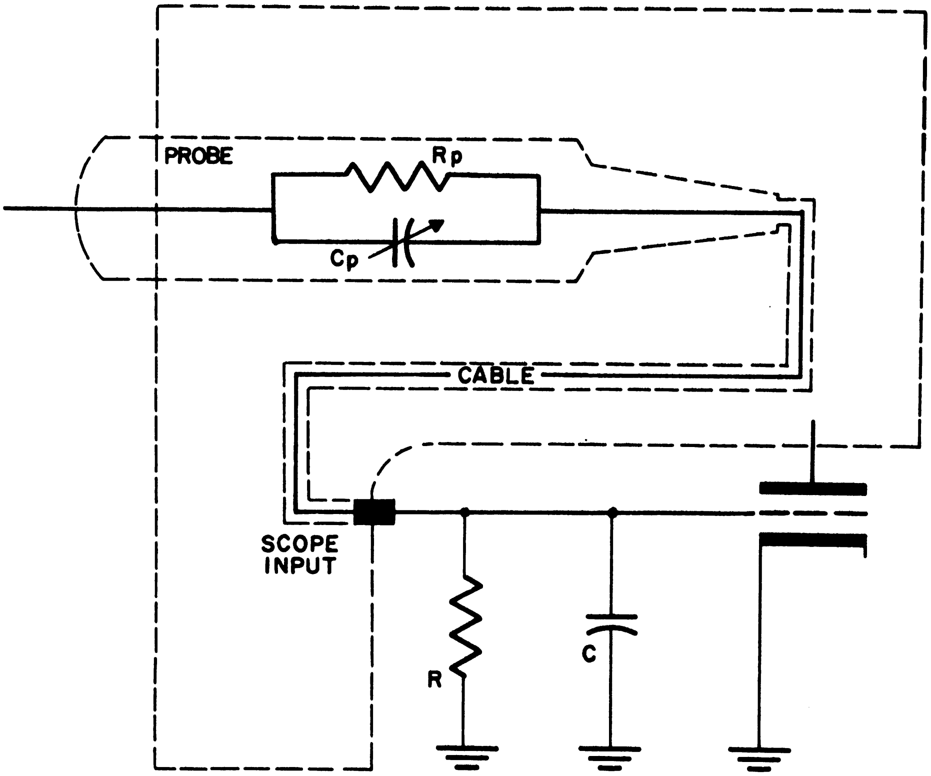


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Figure 17-51.—Oscilloscope vertical amplifier using a passive probe input.

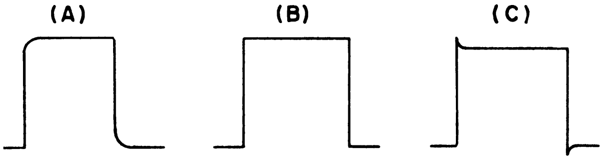

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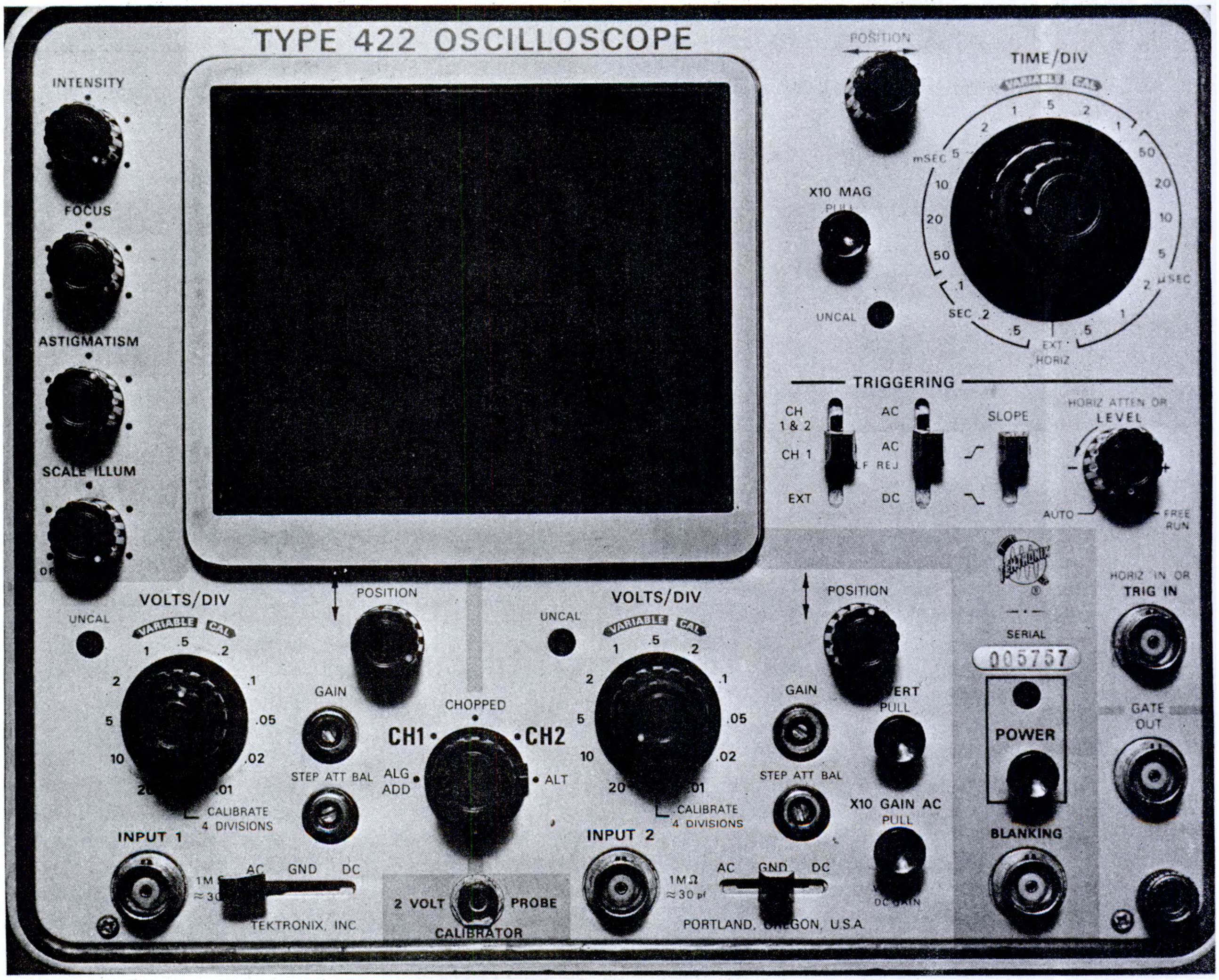
Figure 17-52.—Effects of probe adjustment.

Probe adjustment must be checked whenever a probe is used with an oscilloscope or a plug-in preamplifier that has an input capacitance different from that of the instrument with which the probe was previously used.

NOTE: As indicated in figure 17-52, the attenuation achieved is a result of R as well as R_p, which means that, though probes may be swapped for use with other types of oscilloscopes, the calibration may be in error, even though the waveform distortion may possibly be adjusted out.

TEKTRONIX TYPE 422 OSCILLOSCOPE

The Tektronix type oscilloscope (fig. 17-53) is a transistorized portable oscilloscope capable of operating in a wide range of environmental conditions. The type 422 is lightweight and small, making it easily transported while providing accurate measurements. The dual channel (channels 1 and 2) has a frequency response of d.c. to 15 MHz and provides calibrated deflection factors from 0.01 to 20 volts/division. Stable triggering over the full range of vertical frequency response is provided by the trigger circuits. The horizontal circuits are capable



AQ.604

Figure 17-53.—Tektronix Type 422 oscilloscope.

of a maximum sweep rate of 0.5 microseconds/division (0.05 microseconds/division using X10 magnifier).

The oscilloscope can be powered from a variety of power sources by using a detachable power supply section. With the type 422 a-c power supply the oscilloscope can be operated from an a-c source. Using a type 422 a-c/d-c power supply, the oscilloscope can be operated from either a-c or d-c power supplies or internal batteries.

Operation

Figure 17-54 shows the front panel controls and connectors. Table 17-1 lists the operating panel controls and connectors used in the operation of the Tektronix Type 422 oscilloscope. Column 1 lists the number as illustrated in figure 17-54; column 2 lists the control; and column 3 lists the function and operation of the control.

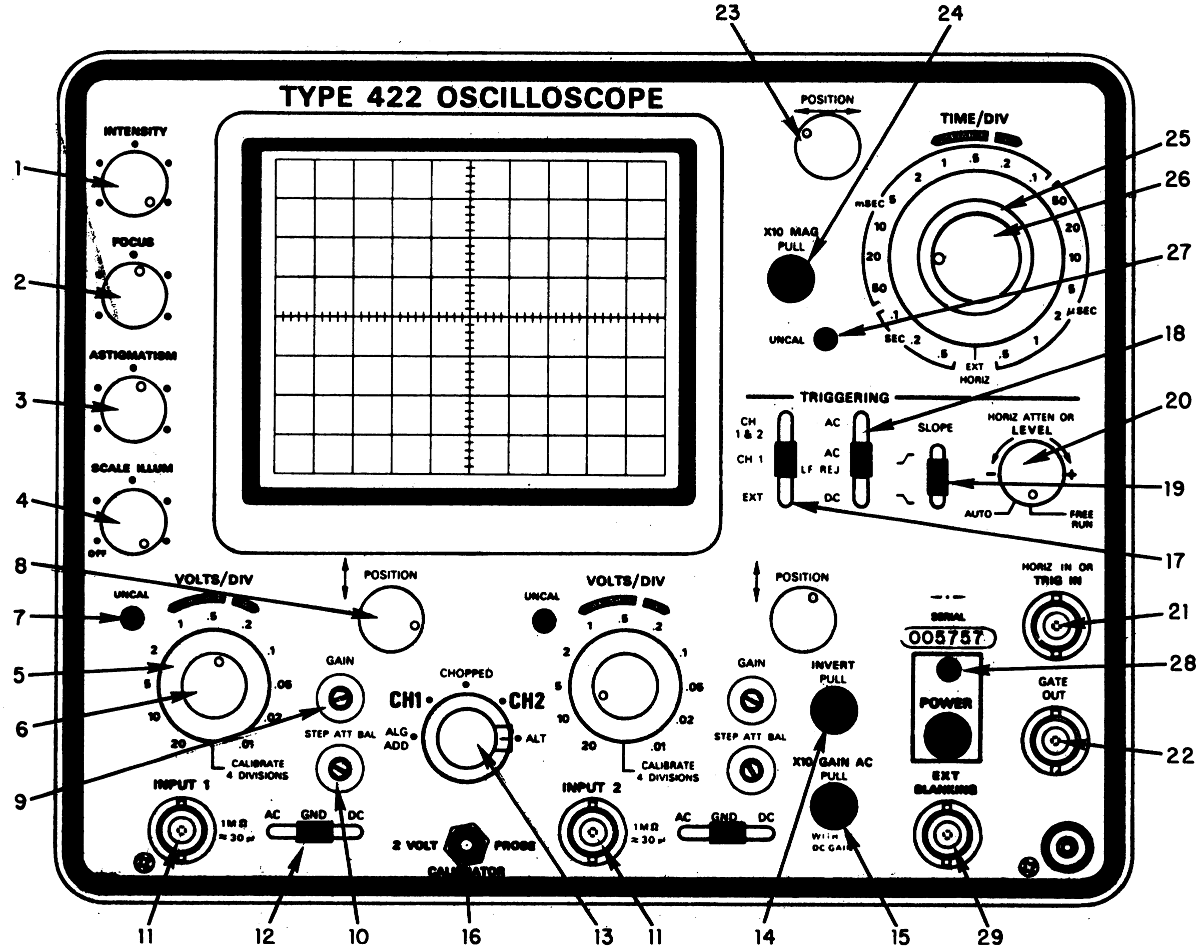


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Figure 17-54.—Tektronix Type 422 oscilloscope front panel controls and connectors.

Table 17-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 17-54).

Number	Control	Function/operation
1	INTENSITY	Controls brightness of display.
2	FOCUS	Provides adjustment to obtain a well-defined display.
3	ASTIGMATISM	Used in conjunction with the FOCUS control to obtain a well-defined display.
4	SCALE ILLUM	Controls illumination of graticule.
5	VOLTS/DIV	Selects vertical deflection factor (VARIABLE control must be in CAL position for indicated deflection.)

Table 17-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 17-54)—Continued.

Number	Control	Function/operation
6	VARIABLE	Provides continuously variable deflection factor to about 2.5 times setting of the VOLTS/DIV switch.
7	UNCAL	Light indicates that VARIABLE control is not set to CAL.
8	POSITION	Controls vertical position of the display.
9	GAIN	Screwdriver adjustment to set the gain of the vertical input amplifier.
10	STEP ATT BAL	Screwdriver adjustment to set the balance of the input amplifier in the .02, .05, and .1 positions of the VOLTS/DIV switch.
11	INPUT	Input connector for vertical deflection signal.
12	AC GND DC	Selects method of coupling input signal to grid of input amplifier. AC: D-C component of input signal is blocked. Low frequency limit (-3 db point) is about 2 hertz. GND: Input circuit is grounded (does not ground applied signal). DC: All components of the input signal are passed to the input amplifier.
13	Mode	Selects vertical mode of operation. ALG ADD: Channel 1 and 2 signals are algebraically added and the algebraic sum is displayed on the CRT. CH 1: The Channel 1 signal is displayed. CHOPPED: Dual trace display of signal on both channels. Approximately -4 microsecond segments from each channel displayed at a repetition rate of about 100 kilohertz.

Table 17-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 17-54)—Continued.

Number	Control	Function/operation
13 (cont.)		CH 2: The Channel 2 signal is displayed.
		ALT: Dual trace display of signal on both channels. Display switched between channels at end of each sweep.
14	INVERT	Inverts the Channel 2 display when pulled out.
15	X10 GAIN AC	Increases a-c gain of Channel 2 amplifier 10 times when pulled out (decreases deflection factor 10 times).
16	2-VOLT PROBE	Output connector providing 2-volt square wave signal for compensating and checking gain of a probe.
17	Source	Selects source of trigger signal.
		CH 1 & 2: Internal trigger signal obtained from displayed channel(s).
		CH 1: Internal trigger signal obtained only from Channel 1.
		EXT: Sweep triggered from signal applied to TRIG IN connector.
18	Coupling	Determines method of coupling trigger signal.
		AC: Rejects d-c signals and attenuates signals below about 50 hertz.
		AC LF REJ: Rejects d-c signals below about 50 kilohertz.
		DC: Accepts both a-c and d-c signals.
19	SLOPE	Selects portion of trigger signal which triggers sweep.
		⎽/⎺: Sweep triggered from positive-going portion of trigger signal.
		⎺\⎽: Sweep triggered from negative-going portion of trigger signal.

Table 17-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 17-54)—Continued.

Number	Control	Function/operation
20	LEVEL	Selects amplitude point on trigger signal where sweep is triggered. When turned fully counterclockwise to the AUTO position, the sweep is automatically triggered. In the FREE RUN position, fully clockwise, the sweep free runs.
	HORIZ ATTEN	(Triggering LEVEL) Provides approximately 10.1 attenuation for external horizontal signals connected to the HORIZ IN connector when the TIME/DIV switch is set to EXT HORIZ.
21	TRIG IN	Input connector for external trigger signal.
	HORIZ IN	(TRIG IN) Input connector for external horizontal signal when TIME/DIV switch is set to EXT HORIZ.
22	GATE OUT	Output connector providing a 0.5 volt or greater negative-going rectangular pulse which is time-coincident with the sweep.
23	POSITION	Controls horizontal position of the display.
24	X10 MAG	Increases sweep rate to 10 times setting of TIME/DIV switch by expanding center division of the display.
25	TIME/DIV	Selects sweep rate of the sweep circuit (VARIABLE control must be in CAL position for indicated sweep rate). In the EXT HORIZ position, horizontal deflection is provided by a signal connected to the HORIZ IN connector.
26	VARIABLE	Provides continuously variable sweep rate to at least 2.5 times setting of the TIME/DIV switch. Sweep rate is calibrated only when control is set fully clockwise to the CAL position.
27	UNCAL	Light indicates that VARIABLE control is not set to CAL.

Table 17-1.—Function/operation of front panel controls and connectors of Tektronix Type 422 oscilloscope (fig. 17-54)—Continued.

Number	Control	Function/operation
28	POWER	Light: Indicates that POWER switch is on and the instrument is connected to a power source. Switch: Applies power to the instrument.
29	EXT BLANKING	Input connector for external blanking signal.

TEKTRONIX TYPE 453 OSCILLOSCOPE

The Tektronix Type 453 Oscilloscope is a lightweight, transistorized portable oscilloscope which has high-frequency capabilities. The input signal range is from d-c to 50 MHz. Input power to the scope is either 115 volts a-c or 230 volts a-c at line frequencies from 45 to 440 Hz. The power consumption is approximately 100 watts.

Some of the capabilities of the 453 oscilloscope are as follows:

1. Display of two independent sweep signals simultaneously.
2. Display a signal which has an intensified portion, and this portion is also displayed as a complete separate sweep.
3. Various-time measurements.
4. Peak-to-peak signal measurements.
5. Voltage measurements of any point of a signal.
6. Voltage comparisons.
7. Frequency measurements.
8. Phase difference measurements.
9. Rejection of unwanted signals.

SYNCHROSCOPE

The synchroscope, which is widely used in radar testing, is an adaptation of the oscilloscope. A trace is produced only when it is initiated by an input trigger, as contrasted with the continuous sawtooth sweep provided by the oscilloscope. Synchroscope circuits are similar to oscilloscope circuits except for the signal channel and the sweep channel. These circuits are shown in block diagram form in figure 17-55.

The signal channel of a typical synchroscope includes an input circuit, which is usually in the form of a 72-ohm adjustable-step attenuator. Various degrees of attenuation are available, and the dial is calibrated to indicate how much attenuation is present. The attenuator insures that all signals, regardless of amplitude, produce approximately the same input level to the amplifier section.

Following the attenuator is an artificial delay line, which is a low-pass filter with a cutoff frequency higher than the highest frequency to be passed, and which has an impedance of 72 ohms. The delay line is terminated with a 72-ohm gain control. One purpose of the delay line is to delay presentation of the signal to be observed until the sweep trace has been initiated by an undelayed portion of the input signal. If the delay line were not used, the initial portion of the waveform would not appear on the trace, because a certain amount of time is required for the input signal voltage to rise to the level needed to trigger the sweep circuit. With the delay line in use, the signal does not reach the amplifier until one-half microsecond after the trace starts; as a result, the entire pulse is seen. A secondary purpose of the delay line is to provide, by means of reflection, a series of accurately spaced pulses suitable for calibration of short time intervals.

To accomplish the secondary purpose, a switch is provided to cause a mismatch in the termination of the delay line. When a sharp pulse is applied into the line, a series of reflections occurs similar to those shown in figure 17-56. Since the time required for a pulse to travel down the line and back is 1 microsecond, a series of pulses occurring 1 microsecond apart is produced. Each successive

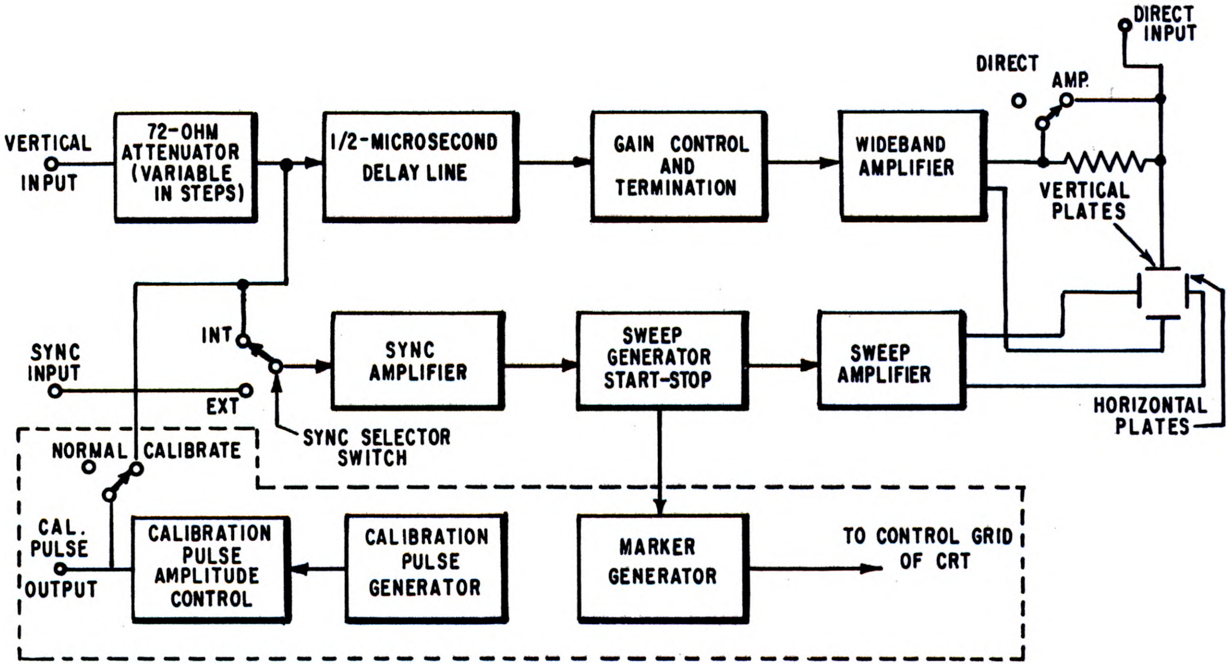

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Figure 17-55.—Typical synchroscope, block diagram.

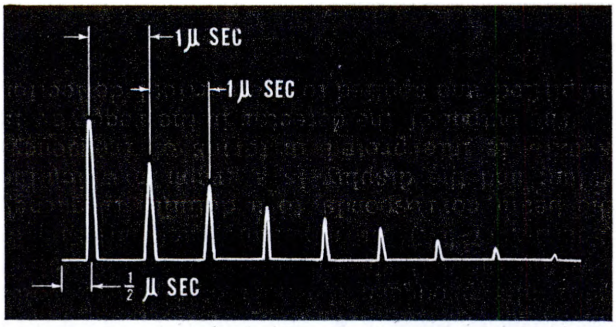

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Figure 17-56.—Pulse reflection on a mismatched line.

pulse is smaller because of the losses in the delay line, but enough pulses are visible for most high-speed calibration purposes.

The gain control feeds a wideband or video amplifier, which is connected to the vertical deflection plates. In addition, an external connection is provided to the vertical plates.

The horizontal circuit consists of a sync switch for either internal or external sync, a sync amplifier with a gain control, and a start-stop sweep generator, which will not develop a sweep voltage until a pulse of sufficient amplitude is supplied. The duration of the sweep, or sweep speed, is made adjustable from a very few microseconds to about 250 microseconds. The sweep generator is followed by a conventional horizontal amplifier. Since the trace is triggered by the input signal, the synchroscope may be used to observe nonperiodic pulses, such as those occurring in a radar system with an unstable PRF generator.

In later designs, it is common to find provisions for calibration of input voltages and sweep time. Voltage calibration is made by comparing the unknown voltage with a variable-voltage pulse of known value, generated internally. The calibrating pulse is adjusted to be equal in amplitude to the unknown voltage; the value is then read from the dial that controls the calibrating pulse. Sweep time calibration is made with the aid of marker pulses produced by accurately adjusted tuned circuits. The marker pulses appear on the trace as a series of bright dots spaced at intervals chosen by the operator. In a typical synchroscope, marker intervals of 0.2, 1, 10, 100, and 500 microseconds may be selected in accordance with the time duration of the pulse under test; for greater accuracy, interpolation may be used.

SPECTRUM ANALYZER

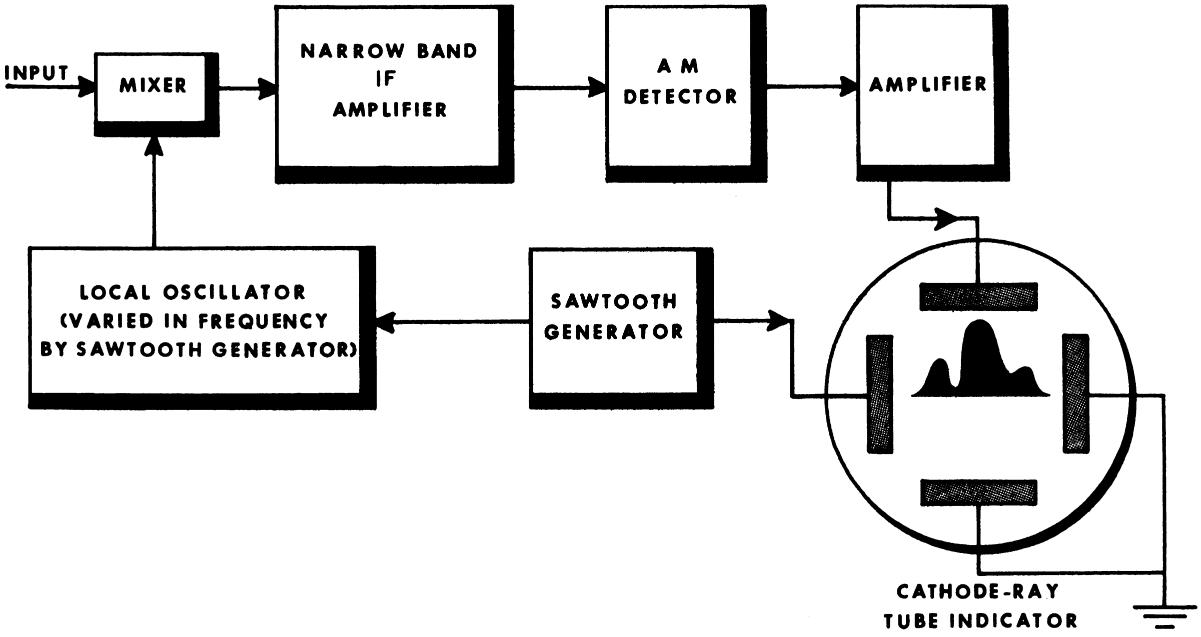
During the modulation of a radiofrequency carrier wave by keying, by speech or music, or by pulses, the resulting wave contains many frequencies. The original carrier is present, together with two groups of new frequencies called the sideband components. One group of sidebands is displaced in frequency below the carrier. The other group is displaced above the carrier. The distribution of these frequencies when shown on a graph of voltage or power against frequency is called the spectrum of the wave.

A spectrum analyzer is a device for exhibiting the spectrum of modulated waves in the radiofrequency range and in the microwave region.

In principle, the spectrum analyzer operates by tuning through the frequency region in question, using a narrowband receiver. The output of the receiver is measured, usually by means of a cathode-ray oscilloscope, and the plot on the screen is a graph of voltage versus frequency.

The device is essentially a superheterodyne receiver with a very narrowband intermediate frequency amplifier section. The local oscillator frequency is varied between two values at a linear rate. The frequency-control generator which governs the frequency of the local oscillator also produces the horizontal sweep voltage for the cathode-ray tube deflection plates. (See fig. 17-57.) As a result, each position of the beam corresponds to a definite frequency value; and the display is a graph in which the X-axis is interpreted in terms of frequency.

The output of the detector in the receiver is amplified and applied to the vertical deflection


INPUT
MIXER
NARROW BAND IF AMPLIFIER
A M DETECTOR
AMPLIFIER
LOCAL OSCILLATOR (VARIED IN FREQUENCY BY SAWTOOTH GENERATOR)
SAWTOOTH GENERATOR
CATHODE-RAY TUBE INDICATOR

AT.133

Figure 17-57.—Typical spectrum analyzer, block diagram.

plates so that the beam is deflected vertically by an amount proportional to the voltage developed in the detector (and amplifier).

The signal to be analyzed is fed into the mixer stage of the receiver. The local oscillator changes in frequency at a linear rate, beating with each of the signal frequency components in succession to form the intermediate frequency of the narrowband amplifier. The output of the IF amplifier is detected, amplified, and applied to the vertical deflecting plates.

Spectrum analyzers designed for analysis of microwave signals are equipped with klystron tubes in the local oscillator stage. In analyzers adapted for lower frequency RF signals, triode oscillators are used which are varied by means of reactance-tube modulators.

Spectrum analyzers are employed extensively in studying the output of pulse radar transmitter tubes such as the magnetron. In this kind of analysis, unwanted effects such as frequency modulation of the carrier can be easily detected. In pure amplitude modulation of a carrier wave by a square pulse, the spectrum is symmetrical about the carrier frequency. Lack of symmetry indicates the presence of frequency modulation. A spectrum representing the ideal condition is shown in (A) of figure 17-58.

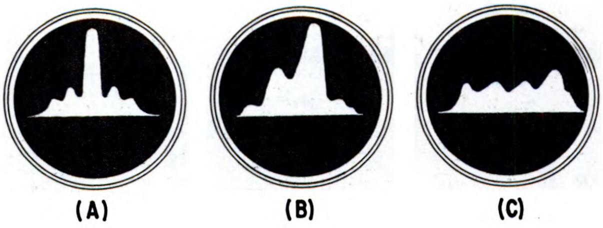


Figure 17-58.—Frequency spectra.

Examples of undesirable magnetron spectra are shown in (B) and (C) of figure 17-58. These forms indicate trouble in the modulator, the tuning system, or in the magnetron tube itself.

The carrier frequency is best defined as the center frequency in a symmetrical spectrum such as that shown in (A) of figure 17-58. In some analyzers this principle is used as a means of carrier frequency measurement. A sharply resonant circuit is provided in the receiver which acts as a trap to prevent an extremely narrow range of frequencies from appearing in the output of the IF amplifier. The result of its use is that a gap appears in the display, and the gap corresponds to the resonant frequency of the trap. The adjustment of the trap is calibrated in frequency, and the circuit can be adjusted to make the gap occur in the center of the spectrum. The frequency of the carrier is then read from the calibration of the trap.

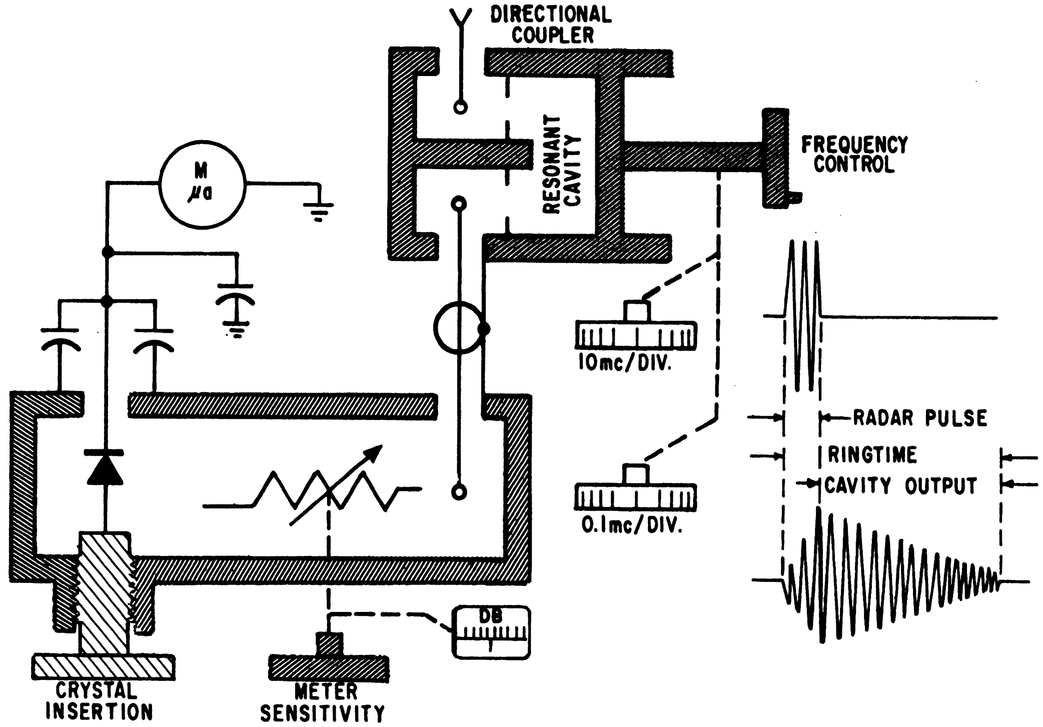
For an additional coverage of spectrum analyzers, consult Basic Electronics. Also, a discussion of spectrum analyzers appeared in the June 1963 issue of the DIGEST. That article is recommended for personnel desiring additional information concerning this class of test equipment.

ECHO BOX

The echo box is used in field testing, troubleshooting, and adjustment of pulsed type radar systems. Although simple in construction and operation, it is versatile in its applications. Properly used within its design limitations, the echo box can frequently eliminate the need for a complex test setup and an elaborate step-by-step testing procedure. The echo box uses passive circuitry, which does not require any external power (other than that of the radar set whose signal is to be analyzed). External power requirement is a critical factor with most other test sets.

The echo box is similar to a tuned cavity frequency meter, with additional capabilities. The tuned cavity frequency meter can be used to measure the frequency of CW or pulsed RF signals in the microwave range. The echo box, however, has no practical application in the testing or analysis of CW equipment signals. Figure 17-59 indicates the basic functional elements of a typical echo box.

Energy from the radar transmitter is fed through the directional couplers to the resonant cavity. When the cavity length is properly adjusted, resonant oscillations are set up by each successive pulse of microwave energy. Maximum amplitude of oscillation occurs when the cavity is tuned precisely to the signal frequency. These cavity oscillations are detected by the crystal diode and indicated on the meter as an average d-c current. The amplitude of oscillation and the average current reading



AT.136

Figure 17-59.—Typical echo box, functional circuit.

are proportional to the transmitter power output.

Oscillations in the tuned cavity are also coupled back to the radar set under test, where it is processed as an echo signal. This signal, when viewed on the indicator CRT, permits analysis of the radar pulse, and presents an indication of the general operating condition of the radar set.

Due to the manner in which the energy builds up in the cavity, saturation of the cavity is possible. If saturation does occur, distortion of the waveform and erroneous values of the measurements result. If the directional couplers do not prevent cavity saturation, additional attenuation must be provided.

A fairly complete functional analysis of the operating condition of a radar set can be obtained through analysis of the displayed waveform. Among the most important of the factors that can be determined are frequency and bandwidth, power and frequency spectra, sensitivity, pulse width and condition, and recovery time. Analysis of the waveform can also prove helpful in locating the cause of malfunctions within the radar set.

It must be remembered, however, that the echo box presents only relative (rather than absolute) values of power and sensitivity, and only rough values of frequency. Accuracy of these quantities is not comparable to the corresponding values obtainable from a spectrum analyzer. The primary value of the echo box lies in its regular usage. For maximum benefit, the values obtained from a given test must be compared to corresponding values obtained from a test on a radar set known to be operating properly.

In general, however, the echo box is an extremely valuable instrument. When used in a continuing maintenance program, it can enable the operator to maintain his equipment in peak operating condition. It can also provide him with indications of deterioration before actual malfunctions occur.

CHAPTER 18
AVIONICS MAINTENANCE

In today's modern high speed aircraft, the aviation weapon systems that are contained in them must be in top operating conditions at all times to insure that the aircraft can complete the mission for which it is designed. The effectiveness of this weapon system depends primarily on the technicians assigned to maintain them. These technicians are only as good as the handtools they use, the publications they use, and last but not least their knowledge of general as well as specific maintenance procedures. In this chapter, general maintenance procedures will be covered that will apply to most avionics systems found in aircraft today.

MAINTENANCE CATEGORIES

The maintenance performed on the equipment falls into two broad categories: (1) actions taken to reduce or eliminate failure and prolong the useful life of the equipment, and (2) actions taken when a part or component has failed and the equipment is out of service. Therefore, maintenance can be considered to consist of preventive maintenance and corrective maintenance.

In maintenance work of any kind, knowledge and skills of two fundamental kinds must be used: First, the technician must have specific information which applies only to the particular equipment for which he may be called upon to repair or keep in good condition; and second, he must possess and be able to use certain general skills and knowledge which apply to many kinds of equipment and types of work assignments.

The specific information required consists of special procedures and processes, and detailed step-by-step directions approved by the proper authority and recommended for a particular piece of equipment. This information is supplied in publications or checkoff lists by Naval Air Systems Command, type commanders, or other authorized sources.

The general maintenance skills and procedures are based on knowledge which is not contained in equipment manuals. These skills must be learned during on the job training and from training manuals such as this one.

PREVENTIVE MAINTENANCE

Maintenance performed to prevent the likelihood of future troubles or malfunctions is usually referred to as preventive maintenance. This form of maintenance consists mainly of visual checks of the equipment prior to and during operation, cleaning the equipment and the various components therein, lubricating, and the periodic inspections.

Visual Checks

Equipment should be checked visually for loose leads, improper connections, damaged or broken components, etc., prior to applying power to the equipment. This applies particularly to new equipment, equipment returned from overhaul, equipment which has been preserved or stored for long periods of time, and equipment which has been exposed to the weather. A close visual inspection should also be conducted on O-rings, gaskets, and other type seals when the equipment under check is a pressurized component. This visual inspection will often reveal discrepancies that may be corrected at that time with a minimum amount of labor and parts. Such discrepancies, if left uncorrected, might result in a major maintenance problem.

Cleaning

Cleaning the equipment and the various components consists of removing dust, grease, and other foreign matter from the covers, chassis, and operating parts. This includes the removal of corrosion, fungus, and all other types of matter which could cause operating failure of the equipment. The methods used to clean the various parts and units will vary, but usually a vacuum cleaner is used to remove the loose dust and foreign matter. The remainder is then wiped or removed with a clean lint-free cloth.

If it is necessary to remove grease or other petroleum deposits, the cloth may be moistened with alcohol or drycleaning solvent. After removing the grease, the part should be wiped dry, or allowed to dry by evaporation prior to applying power.

Lubrication

Lubrication of electronic equipment consists of lubricating the mechanical parts which are associated with the electronic equipment. Equipment which may need periodic lubrication, such as unsealed bearings, antenna drives, waveguide rotating joints, etc., should be lubricated as directed by the equipment's Maintenance Instructions Manual. The specification number of a lubricant should be strictly followed, as the viscosity of a lubricant will change with a change in operating temperature. High operating temperatures cause lubricants to become thin, while low operating temperatures cause lubricants to thicken or harden. Therefore, the lubricant used for a particular job will depend on the operating characteristics and temperature. Particular attention should be paid to equipment lubrication where the aircraft is flown at high altitudes. A special lubricant should be used which will not harden and cause a physical overload on the drive motors and shafts, and an electrical overload on the circuits involved.

CORRECTIVE MAINTENANCE

When defective parts or unsatisfactory operation have been revealed, it is necessary to analyze the equipment, find the defective part or parts, and make the appropriate replacement or repair. In general, the most effective method for this analysis is a careful and logical step-by-step troubleshooting procedure.

TROUBLESHOOTING

Much of the technician's time is spent troubleshooting the equipment in the squadron's aircraft. The technician's job is to maintain a great number of units and systems, many of which are quite complex, and which might seem at a glance beyond his ability to maintain. However, the most complex job usually becomes much simpler if it is first broken into successive steps. Any maintenance job should be performed in the following order:

1. Analyze the symptom.
2. Detect and isolate the trouble.
3. Correct the trouble and test the work.

AIRCRAFT PROCEDURES

In troubleshooting, as in most other things, there is no substitute for commonsense. A mistake made by most beginners is to remove major units from the aircraft unnecessarily. When a discrepancy is received, the first step is to determine if the equipment in question is actually faulty. Very often a preliminary check of the system in the aircraft will disclose a faulty control box, frayed or broken wiring, corroded or wet connectors, and, in rare cases, improper operating procedure—especially with new equipment. (Improper operating procedures are especially common when the reported discrepancy involves new equipment or personnel undergoing indoctrination.)

If there is no power present at the input to the equipment, it may be assumed (temporarily) that the set is not defective. Check all applicable switch positions, circuit breakers, fuses, etc., then check for power at the bus which feeds the equipment. Check the tightness and the physical condition of interconnecting cables. Using the wiring diagrams in the applicable manuals, check at successive tie points and splices for continuity, short circuits, or grounds. The procedures to be followed with these tests are discussed later in this chapter under the heading Basic Tests.

If a circuit breaker is tripped or if a fuse is blown, a circuit malfunction is indicated. Power to the circuit containing the "open" should be turned off, and should not be reapplied until the malfunction is located and corrected. The most common causes of tripped or blown circuit protectors are short circuits, faulty grounds, or overload conditions. However, circuit protectors sometimes fail due simply to age or to transient conditions. If, after a thorough check, no apparent reason for the failure can be found, the breaker may be reset or the fuse replaced with the proper size and type, and the power reapplied. If the protector fails again, a malfunction is definitely indicated.

If the analysis does not indicate the existence of a short circuit, faulty ground, or overload condition, but the equipment still does not operate, continue to take measurements with power applied. These measurements should be taken systematically at progressive checkpoints. Particular faults which may interrupt current through a circuit include broken wiring, loose or faulty terminal or plug connections, faulty relays or switches, and uncoupled splices. Be alert for these conditions.

If the defective unit cannot be identified while still installed in the aircraft, it may be advisable to turn off the power and substitute units one at a time with units which are known to operate properly. As each unit is replaced, power should be reapplied and the system checked for operation or for symptoms of nonoperation. If the system operates normally, the faulty unit has been identified, and the faulty unit may be taken to the shop for corrective maintenance. At this stage of the overall maintenance process, it is also advisable to try to determine the reason for the failure of the unit—it is conceivable that the new unit may also be damaged if the basic cause is not corrected.

Following removal of the defective unit and the subsequent analysis, all other items of the original installation should be reinstalled and safety wired, and an operational check performed. During the operational check, any readjustments or calibrations should be accomplished as required. This should be done prior to clearing the discrepancy on the Maintenance Action Form.

Basic Tests

Several rules are set forth below and are intended as a guide to follow when making the tests described in this section.

1. Always connect an ammeter in series.
2. Always connect a voltmeter in parallel.
3. Never connect an ohmmeter to an energized circuit.
4. Select the highest range first then switch to lower ranges as needed.
5. When using an ohmmeter, select a scale that will result in a midscale reading.
6. Do not leave the selector switch of a multimeter in the resistance position when the meter is not in use because the leads may short together and discharge the internal battery. There is less chance of damaging the meter if it is left on a high a-c volts setting or in the off position if it has one. Meters that have an off position dampen the swing of the needle by connecting the meter movement as a generator. This prevents the needle from swinging wildly when the meter is moved.
7. View the meter from directly in front to eliminate parallax.
8. Observe polarity when measuring d-c voltage or direct current.
9. Do not place meters in the presence of strong magnetic fields.
10. Never attempt to measure the resistance of a meter or a circuit with a meter in it as the high current required for ohmmeter operation may damage the meter. This also applies to circuits with low-filament current tubes and some types of semiconductors.
11. When measuring high resistance, be careful not to touch the test lead tips or the circuit as body resistance will shunt the circuit and give an erroneous reading.
12. Connect the ground lead of the meter first when making voltage measurements. Work with one hand whenever possible.

CONTINUITY TEST.—Open circuits are those in which the flow of current is interrupted by a broken wire, defective switch, or any means by which the current cannot flow. The test used to check for opens (or to see if the circuit is complete or continuous) is called continuity testing.

An ohmmeter (which contains its own batteries) is excellent for a continuity test. In an emergency, a continuity tester can readily be made from a flashlight. Normally, continuity tests are performed in circuits where the resistance is very low (such as the resistance of a copper conductor). An open circuit is indicated by a very high or infinite resistance. Such a condition would be an open conductor.

The diagram in figure 18-1 shows a continuity test of a cable. Note that both connectors are disconnected and the ohmmeter is in series with the conductor under test. The power must be off. Checking conductors A, B, and C, the current from the ohmmeter will flow through plug No. 2, through the conductor, and plug No. 1. From this plug it will pass through the jumper to the chassis which is "grounded" to the aircraft's structure. The structure will serve as the return path to the chassis of unit 2 completing the circuit to the ohmmeter. The ohmmeter will indicate a low resistance.

Checking conductor D (fig. 18-1) will reveal an open. The ohmmeter will indicate maximum resistance because current cannot flow. With an open circuit, the ohmmeter needle is all the way to the left since it is a series type ohmmeter (reads right to left).

Where conditions exist that the aircraft structure cannot be used as the return path, one of the other conductors may be used. For

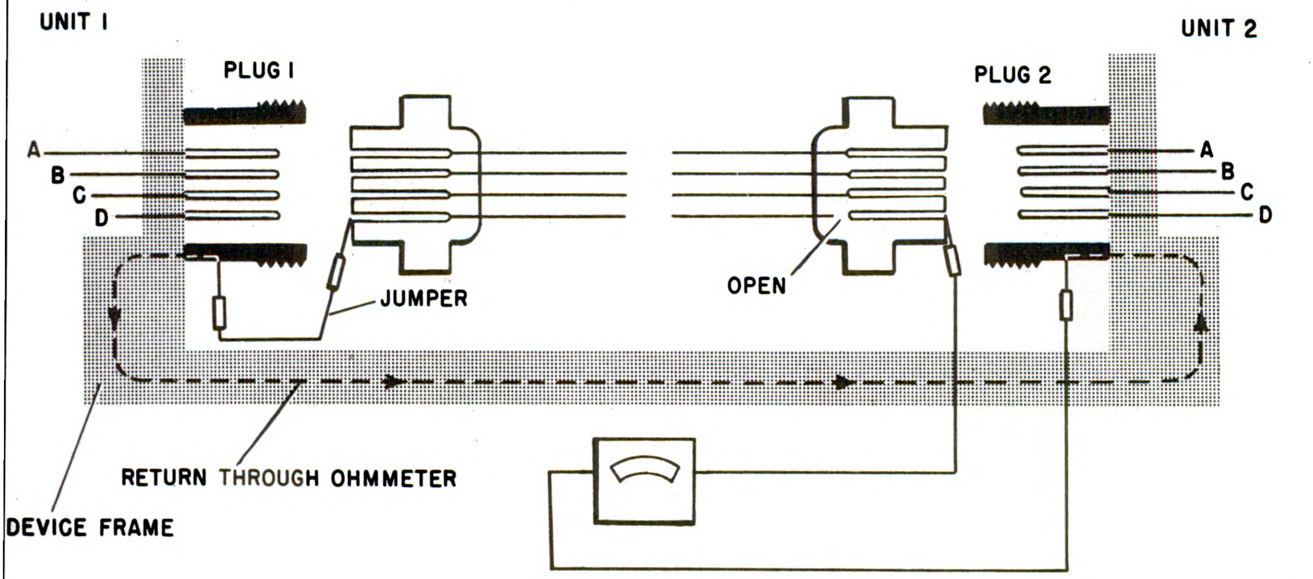


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Figure 18-1.—Continuity test.

example, to check D (fig. 18-1) a jumper is connected from pin D to pin A of plug 1 and the ohmmeter leads are connected to pins D and A of plug 2. This technique by the process of elimination will also reveal the open in the circuit.

GROUNDED CIRCUIT TEST.—Grounded circuits are caused by some conducting part of the circuit making contact either directly or indirectly with the metallic framework of the aircraft. Grounds may have many causes, the most common of which is perhaps the fraying of insulation from a wire allowing the bare wire to come in contact with the metal ground.

Grounds are usually indicated by blown fuses or tripped circuit breakers. Blown fuses or tripped circuit breakers, however, may also result from a short other than ground. A high resistance ground may also occur where sufficient current does not flow to rupture the fuse or open the circuit breaker.

In testing for grounds, the ohmmeter is used. Other continuity testers may also be used. By measuring the resistance to ground of any point in a circuit, it is possible to determine if the point is grounded. By considering figure 18-1, one possible means of testing a cable for grounds can be seen. If the jumper is removed from pin D of plug No. 1, a test for grounds is made for each conductor of the cable. This is accomplished by connecting one meter lead to ground and the other to each of the pins of one of the plugs. A low resistance will indicate that a pin is grounded. Both plugs must be removed from their units; if only one plug is removed, a false indication is possible for a conductor may be grounded through the unit.

SHORT TEST.—A short circuit, other than a grounded one, is one where two conductors accidentally touch each other directly or through another conducting element. Two conductors with frayed insulation may touch and cause a short. Too much solder on the pin of a connector may short to the adjacent pin. In a short circuit, sufficient current may flow to blow a fuse or open a circuit breaker. However, it is entirely possible to have a short between two cables carrying signals; such a short may not be indicated by a blown fuse.

As when checking for a ground, the device used for checking for a short is the ohmmeter. By measuring the resistance between two conductors a short between them may be detected by a low resistance reading. In figure 18-1 by removing the jumper and disconnecting both plugs, a short test may be made. This is performed by measuring the resistance between the two suspected conductors.

Shorts are not reserved for cables, they occur in many components, such as transformers, motor windings, capacitors, etc. The major test method for testing such components is a resistance measurement, and then comparing the indicated resistance with the resistance given on schematics or in maintenance manuals. Comparison could also be made with identical operational equipment.

VOLTAGE TEST.—The voltage test must be made with the power applied; therefore, the prescribed safety precautions must be followed to prevent injury to personnel and damage to the equipment. The technician will find in his maintenance work that the voltage test is of utmost importance. It is used not only in isolating casualties to major components but also in the maintenance of subassemblies, units, and circuits. Before checking a circuit voltage, a check on the voltage of the power source should be made to be sure that the normal voltage is being impressed across the circuit.

BENCH PROCEDURES

The visible condition of a unit is usually the first thing to check in any process of troubleshooting. If certain parts are obviously not in proper condition, these faults must be corrected before going any further in the tests. Such conditions include parts which are burned, loose from their mountings, disconnected, dented, broken, or otherwise obviously faulty. This step should be accomplished prior to installing and connecting the unit at the test bench.

The sense of smell can be helpful in pinpointing certain troubles. A part that overheats usually gives off an odor that is readily detectable, and can sometimes be located by the odor given off. However, location of a burned part does not necessarily reveal the cause of the trouble.

In determining the cause of the trouble, it is usually necessary to refer to the Maintenance Instructions Manual. This manual will be a valuable source for constant reference when performing maintenance on electronic equipment. Few technicians are so thoroughly familiar with an electronic unit that they do not have to use the manual when performing maintenance.

Signal Tracing

The following procedure is given for tracing signals in RF receivers and audio amplifiers; however, this general procedure, with modifications, can be applied to most electronic troubleshooting. In radar the frequencies are higher, the methods of signal application differ, and the output in the final stage is video (viewed) on a scope, instead of audio (heard) from a speaker or headset. The applicable Maintenance Instructions Manual contains detailed procedures for testing most units or circuits.

Signal tracing is a very effective method for locating defective stages in many types of electronic sets. It is especially useful when servicing equipment which normally contains no built-in meters. In signal tracing, a signal voltage (similar to that which is present under operating conditions) is taken from a signal generator and is then applied to the input of the circuit in question. The signals which result are then checked at various points in the stage, using test instruments such as vacuum tube voltmeters, oscilloscopes, output meters, or any high impedance instrument which is appropriate. (The test instrument should have high impedance so that it will not change the operation of the circuit to which it is applied.)

When using the signal tracing technique to measure a-c signals, be sure that the test instruments are adequately isolated from any d-c potentials present in the circuit. Some test instruments are equipped with special a-c probes which incorporate a capacitor in series with the input; other equipments are not so equipped. Before using any item of test equipment, the technician must familiarize himself with the characteristics and proper use of the test equipment, as well as with the equipment under test.

By signal tracing methods, the gain or loss of amplifiers can be measured; and the points of origin of distortion and hum, noise, oscillation, or any abnormal effect can be localized.

The gain measurement can be used as an example of an important method in signal tracing. By this procedure, a defective stage can be found quickly. A signal generator, with the output attenuator calibrated to microvolts, and an output meter are used. It is helpful to have data concerning the normal gain of the various stages of the device. This data is generally found in the Maintenance Instructions Manual for the receiver under test.

The output meter may be connected across the headset (or the voice coil of a speaker) or across the secondary of the output transformer. The output of the signal generator is applied to the grid circuit of the stage under test. The attenuator of the signal generator is then adjusted until the output meter reads a value appropriate to serve as a reference figure. The output of the signal generator is then applied to the output of the stage under test (or to the input of the next stage), and the attenuator is adjusted until the same reference value is again registered on the output meter. The gain of the stage is found by dividing the second value of the signal (taken from the calibrated attenuator) by the value of the signal applied to the input of the stage.

As an example, suppose the signal generator supplies a voltage of 400 microvolts to the grid of an IF amplifier. This voltage causes the output meter to indicate some value that can be used as a reference. When the generator signal is applied to the following grid, the signal strength must be increased (to 4,000 microvolts) to cause the output meter to indicate the same reference value. The gain of the stage is equal to

$$\frac{E_{in}\ \text{2nd stage}}{E_{in}\ \text{1st stage}}\text{; that is, } \frac{4{,}000}{400} = 10$$

If similar measurements made in the remaining stages of the receiver reveal one stage in which the gain is lower than normal or is zero, that stage can then be thoroughly checked by voltage measurement, by the resistance measurement, or by simple replacement of parts until the defective one is found.

Test Probe Substitution

Using a test equipment probe with equipment other than that for which it was designed may result in considerable error. Any differences in the internal resistance of the probe and input circuitry of the equipment precludes substitution without calibration. For example, the internal resistance of a 10:1 probe is, in most cases, nine times higher than the input circuitry of the equipment. It should be noted that 2:1, 50:1, and 100:1 probes are available as well as 10:1 probes.

Test probes which are not recommended for specific equipments should not be used, because they may not have sufficient capacitive adjustment to preserve the waveshape of the observed signal. A sound rule is to use all test probes only with the equipment for which they were designed.

Voltage Checks

Voltage measurements are made at various points in the stage suspected of being at fault, and the observed voltage values are compared with the normal voltage values given in the Maintenance Instructions Manual.

When making voltage checks for comparison with a chart, be sure to use a voltmeter with the proper ohms-per-volt rating (sensitivity). Voltmeters are connected in shunt with the circuit elements under test, resulting in circuit loading. (Circuit loading is discussed in Basic Electronics.) If the sensitivity of the test instrument is the same as that of the instrument used in making the readings on the chart, the loading effect will be the same in both cases, and the readings obtained are reliable. Another important point to remember is that if the meter sensitivity is too low, loading effect may be so severe as to prevent proper operation of an otherwise normally functioning circuit.

From this comparison, the defect can often be isolated. Voltage checks are most effective when applied within a single stage, after previous checks have been made to localize the defect. This is true because modern electronic equipment is complex, and a great deal of time is required to check all the voltages present in all the stages.

Some electronic sets have built-in meters or plugs for front panel application of meters. These meters usually work in conjunction with a selector switch, and will read values of voltage or current at designated points. A defective stage can often be isolated in this manner.

Once the defective stage is isolated, it becomes a matter of point-to-point checking to isolate the fault within the stage itself. A voltmeter will pinpoint the trouble, but it often becomes necessary to use an ohmmeter to determine the exact cause of trouble, such as shorted capacitors, open resistors or transformers, or wire grounded to chassis.

Resistance Checks

Resistance checks are similar to voltage checks except that the power is removed from the set. Resistance values are measured with an ohmmeter, and the readings are compared with the normal values given in the maintenance publications. Resistance checking, like voltage measurement, is most effective after the trouble has been isolated to a particular stage. Reliance on resistance measurement alone is too time consuming to be efficient. After the trouble has been isolated, the ohmmeter is a very useful instrument and often quickly leads the technician to the cause of the trouble.

NOTE: In order to prevent damage to the ohmmeter, always be sure that there are no voltages present in the equipment prior to beginning the resistance checks. Turn off the power switches, discharge power supply and other large capacitors, and bleed off any other residual charges in the set. Also observe proper precautions when connecting or disconnecting the ohmmeter across large inductors.

A typical example of a routine resistance check applied to a single part is the ohmmeter method of checking electrolytic capacitors. A resistance measurement is made on the discharged capacitor, using the high resistance range of the ohmmeter. When the ohmmeter leads are first applied across the capacitor, the meter pointer rises quickly and then drops back to indicate a high resistance. The test leads are then reversed and reapplied. The meter pointer should rise again—even higher than before—and again drop to a high value of resistance. The deflections of the meter are caused when the capacitor is charged by the battery of the ohmmeter. When the leads are reversed, the voltage in the capacitor adds to the applied voltage, resulting in a greater deflection than at first.

Do not leave the ohmmeter connected across an electrolytic capacitor for any appreciable period of time. Electrolytic capacitors are polarity-sensitive, and reverse polarity of voltage (even from an ohmmeter) may cause excessive current which could result in overheating and possible explosion of the capacitor.

If the capacitor is open-circuited, no deflection will be noted. If the capacitor is short-circuited, the ohmmeter indicates zero ohms. The resistance values registered in the normal electrolytic capacitor result from the fact that there is some current leakage between the electrodes. Because the electrolytic capacitor is a polarized device, the resistance is greater in one direction than the other.

Should a capacitor indicate a short circuit, one end of it must be disconnected from the circuit and another resistance reading taken to determine if the capacitor is actually at fault.

Unless the ohmmeter has a very high resistance scale the deflection of the meter when checking small capacitors will not be noticeable. Even a scale of R x 10,000 is not sufficient for very small capacitors; the smaller the capacity the less leakage across the plates, therefore the more resistance.

When making resistance checks, be sure to determine what circuits are connected to the points where the checks are made. The Maintenance Instructions Manual will indicate what resistance should be found at various checkpoints throughout the set, and will contain a complete schematic of the set as well as a circuit schematic of the stage under test. The schematics may set up conditions under which voltage and resistance measurements are to be made, such as positions of switches and control knobs, relays energized or deenergized, tube in socket, etc. These conditions will duplicate the conditions under which the measurements were first made. A typical condition might be: "Power switch OFF—all controls on the control box fully CCW (counterclockwise)." It is important that these instructions be followed to obtain accurate values to compare with specified values. Otherwise incorrect values may be obtained.

Defective Components

Before replacing a defective part it is necessary to determine if such an operation may be performed by the squadron. This is determined by the level of maintenance that has been assigned to the squadron. Increasing complexity and compactness of electronic equipment have resulted in a trend toward replacement of subassemblies rather than individual parts. This trend is caused by the necessity of exact parts replacement, and the difficulty of working in small spaces where even the amount of solder used on a connection can be of importance. However, there are many parts that may be replaced at any level of maintenance. The general rule is to replace any defective part with an exact duplicate.

Publications may be consulted to aid in obtaining information (such as stock number and description) about a particular part. The publications which will most often be used when ordering parts are the IPB and the Section R list for the particular equipment under repair. Chapter 4 of this training manual explains the use of the IPB and the Section R lists, and also the Standard Aeronautical Electronics Material Section R, NavAir 00-35QR-4.

Should it become necessary to replace a part with a substitute, the technician must make sure that the substitute part is a proper replacement. With resistors, for instance, several characteristics must be considered—ohmic value, wattage rating, tolerance, physical size, and type of construction. Capacitors involve consideration of physical size, capacity, tolerance, temperature coefficient, and voltage rating. Plugs and connectors will almost invariably have to be exactly as prescribed since it is difficult to find items of this type that are interchangeable. Familiarity with the IPB is a definite asset to the technician who must determine exactly what part to order.

Basic Electronics contains information on color codes for capacitors and resistors. Refer to this manual for information on standard codes, specifications, physical shapes, methods of reading, and tolerances.

Checking After Repair

No repair job is complete until the repaired unit or component is reinstalled and actually operating properly. The component must be bench checked after the trouble is remedied, usually before the component is completely reassembled, and any alinement adjustments necessary to assure proper operation should be made. After reassembly of the component—replacement of dust and shielding covers, installation of component in outer case (and pressurization if necessary)—a final bench operational check should be performed. Oftentimes a shield or plate that has been installed will touch a bare wire or other contact and will render the component inoperative or cause substandard operation. It is much better to discover such a fault at the bench than in the aircraft.

After the component is reinstalled in the aircraft and properly secured for flight, it must be given a final operational test. It cannot be assumed that because the component operated properly on the bench it will do so in the aircraft. The most important test is an operational check under exact operating conditions. When the component performs properly in the aircraft and is securely mounted, the discrepancy sheet may be signed. This signature indicates that the electronic component should operate properly under normal flight conditions.

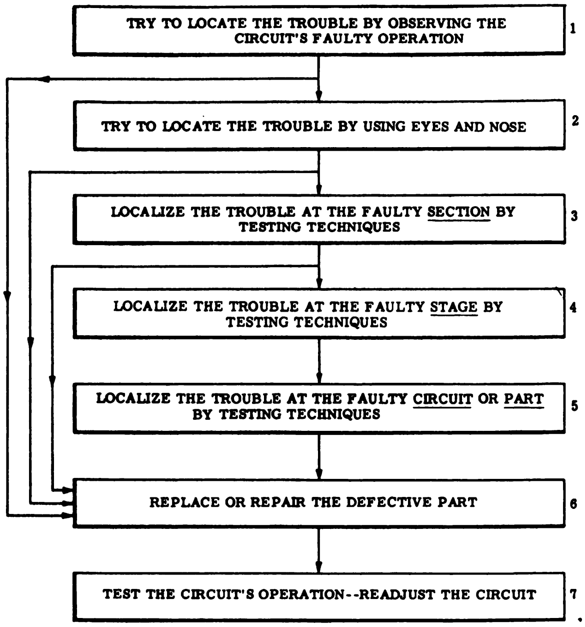
TRY TO LOCATE THE TROUBLE BY OBSERVING THE CIRCUIT'S FAULTY OPERATION
1
TRY TO LOCATE THE TROUBLE BY USING EYES AND NOSE
2
LOCALIZE THE TROUBLE AT THE FAULTY SECTION BY TESTING TECHNIQUES
3
LOCALIZE THE TROUBLE AT THE FAULTY STAGE BY TESTING TECHNIQUES
4
LOCALIZE THE TROUBLE AT THE FAULTY CIRCUIT OR PART BY TESTING TECHNIQUES
5
REPLACE OR REPAIR THE DEFECTIVE PART
6
TEST THE CIRCUIT'S OPERATION--READJUST THE CIRCUIT
7

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Figure 18-2.—Troubleshooting procedure.

The troubleshooting information described in the preceding paragraphs is summarized in figure 18-2, which shows in chart form a general troubleshooting procedure. The directions given in blocks 1 through 5 are steps to be used in locating trouble, and the directions given in blocks 6 and 7 are steps in repairing the set. (Steps 2, 3, 4, and/or 5 may sometimes be eliminated, but steps 6 and 7 will always be followed.)

REPAIR INFORMATION

As was mentioned previously, increasing complexity and compactness of electronic equipment have caused a trend toward replacement of subassemblies rather than individual parts. This trend is caused by the necessity of exact parts replacement, and the difficulty of working in small spaces where even the amount of solder used on a connection can be of importance. However, there are many parts that will need to be replaced, and the rule is to replace a defective part with an exact duplicate.

The trend toward replaceable units has led to several new methods of construction of electronic equipment. Two examples are MICROELECTRONICS and PRINTED CIRCUITS. These circuits are designed for speed and economy of manufacture, and speed and ease of maintenance, as well as saving of space and weight.

SOLDERING

Soldering operations are a vital part of electronics maintenance procedures. It is a manual skill which can and must be learned by all personnel assigned electronics maintenance shop duties. Practice is required to develop proficiency in the techniques of soldering; however, practice serves no useful purpose unless it is founded on a thorough understanding of basic principles. For a discussion on soldering materials and practices, refer to chapter 7 of Basic Electricity, NavPers 10086-B.

MICROMAINTENANCE

Microelectronic technology by itself will not solve the maintenance problem. In spite of the greatly increased reliability, failures will still occur. When they do, the faulty items must be isolated and repaired or replaced.

With the discrete miniature component (transistor, resistor, capacitor, etc.), the maintenance technician can test individual circuit elements and thus determine the cause of failure. Repairs can then be made by replacing the faulty component.

With the integrated circuit, replacement of an individual part is impossible because the unit is designed and exists only as a complete functional element. The maintenance process then becomes a matter of isolation and replacement of the defective "chip," "flat-pack," board, or module.

Modules

Modular assemblies are mechanically more rugged than conventional circuits. They are, however, susceptible to damage from improper handling, electrical overload, or overheating. Techniques of maintenance and servicing are similar to those used with conventional circuits, but require somewhat more care in execution.

The small size and close spacing of the parts within the assembly require more care and smaller tools than are normally required in conventional maintenance. Additional devices and maintenance aids are of great help in developing the precision needed for such close work. Many components are inherently susceptible to damage from various causes. These factors require modification of some of the basic maintenance techniques and the use of some new ones.

Component damage during maintenance is usually the result of excess heat during repair, reversed polarity of ohmmeters while checking for continuity, application of excessive voltages or signal magnitudes during testing, rough handling, or use of the wrong tools or materials.

Loosening connections, disconnecting parts, inserting or removing transistors, and changing modular units should not be done with the power on or while the circuit is under test. These actions (or a loose connection of any type) will cause an inductive kickback, which may damage the component.

It is also important to remove any capacitive charge from parts, tools, or test equipment before connecting them to any modular unit. A grounding clip should be connected from the item to the modular chassis before making any other contact. When disconnecting, the grounding clip should be removed last.

Leads to transistors, printed circuit boards, etc., as well as many miniature components, are easily damaged in handling, stowage, or shipping. Proper precautions should be used at all times.

It should be emphasized that these miniature components and circuits can be repaired, if adequate care and proper techniques are used.

Maintenance Aids

In maintenance of microcircuits special devices are needed to extend the vision, aid the reach, and act as a third hand for the technician. Special tool and device requirements depend on the equipment to be serviced and on the maintenance operations involved. Many of the tools and devices discussed in this section are useful in all maintenance activities; others have limited applicability. The assortment of tools should be kept to the minimum required for effective and efficient maintenance of assigned equipment.

Many dental implements no longer usable for their original purpose can be readily adapted for use by the technician. These include various knives for scraping protective coatings and excess solder, brushes for cleaning, probes and mirrors for inspecting in crowded spaces, and drills for making small repairs. Tweezers and surgical hemostats are useful for grasping and holding small parts. Although they may also be used as heat shunts in soldering, their effectiveness is limited. A more desirable heat shunt is described later in this section. Hypodermic syringes are useful in oiling hard-to-reach points.

A pin vise is useful in drilling through plastic, bakelite, or the copper-ribbon conductor strips of a printed circuit board. It may also be used to clean solder from hallow receptacles and terminals. In addition, it can hold many sizes and shapes of hooks and probes made from spring wire. These attachments are useful in inspection and servicing in confined spaces.

A magnifying device for inspecting minute parts is essential. If the magnifier is mounted on a stand, it leaves the technician with both hands free for other tasks.

When working on a printed circuit or terminal board which has been removed from its mounting, the work must be held firmly. A module holder or module jig is suitable for this purpose. The jig will provide support and prevent flexing or slipping. Securing the jig to the worktable leaves the technician with both hands free during the maintenance process.

For any desoldering operation, the part should be mounted so that the terminals are pointed out and downward. Place the soldering iron under the terminals so the solder flows away from the joint. To resolder the joint, invert the part.

A drawer or box with a white cloth can be used to catch any small parts dropped during maintenance. A drawer and sheet (or a cigar box and handkerchief) should prove adequate. (See fig. 18-3.) When attaching the cloth, leave a little slack to form a pocket in the middle. When the jig is mounted immediately above the trap, any part dropped should find its way to the center of the cloth.

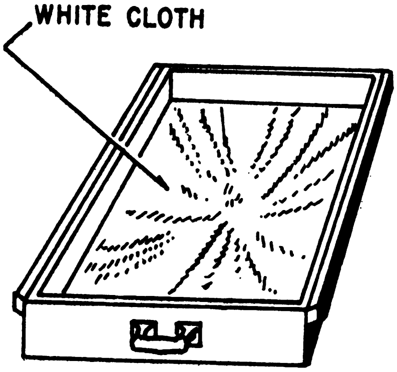

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Figure 18-3.—Trap for catching dropped parts.

PRINTED CIRCUITS

The trend toward replaceable units has led to several new methods of construction of electronic equipment, an example of which is the printed circuit. This type circuit is designed for speed and economy of manufacture, and speed and ease of maintenance, as well as the saving of space and weight.

Circuit Construction

One method of manufacturing a printed circuit is the "photoetching" process. A plastic or phenolic sheet with a thin layer of copper coating may be used. The copper coating is covered with a light-sensitive enamel, and a template of the circuit that will ultimately appear on the plastic sheet is placed over it. The entire sheet is then exposed to light. The area of the copper that is exposed reacts to the light. This area is then removed by an etching process. The exposure of the printed circuit is similar to a photographic exposure. The enamel on the unexposed circuit protects the unexposed copper from the etching bath that removes the exposed copper. After the etching bath, the enamel is removed from the printed circuit. This leaves the surfaces in a condition for soldering parts and connections.

Some manufacturers use machinery to mount standard parts like capacitors, resistors, and tube sockets—further speeding manufacture. Circuits thus produced operate as well as conventional circuits and are as easily repaired.

Figure 18-4 shows an improved type of construction, from the troubleshooter's standpoint, consisting of a removable subassembly of the type called "modules." These modules are readily removable and have numerous internal and external test points to facilitate troubleshooting. The modules are built of standard parts that are easily replaceable. Most test racks have plug extensions that permit any module to be raised, making all parts accessible for checking and repairing. The module is not expendable but can be easily repaired, since all parts are of conventional design. Miniature and subminiature parts are so common in today's electronic equipment that they are considered to be conventional.

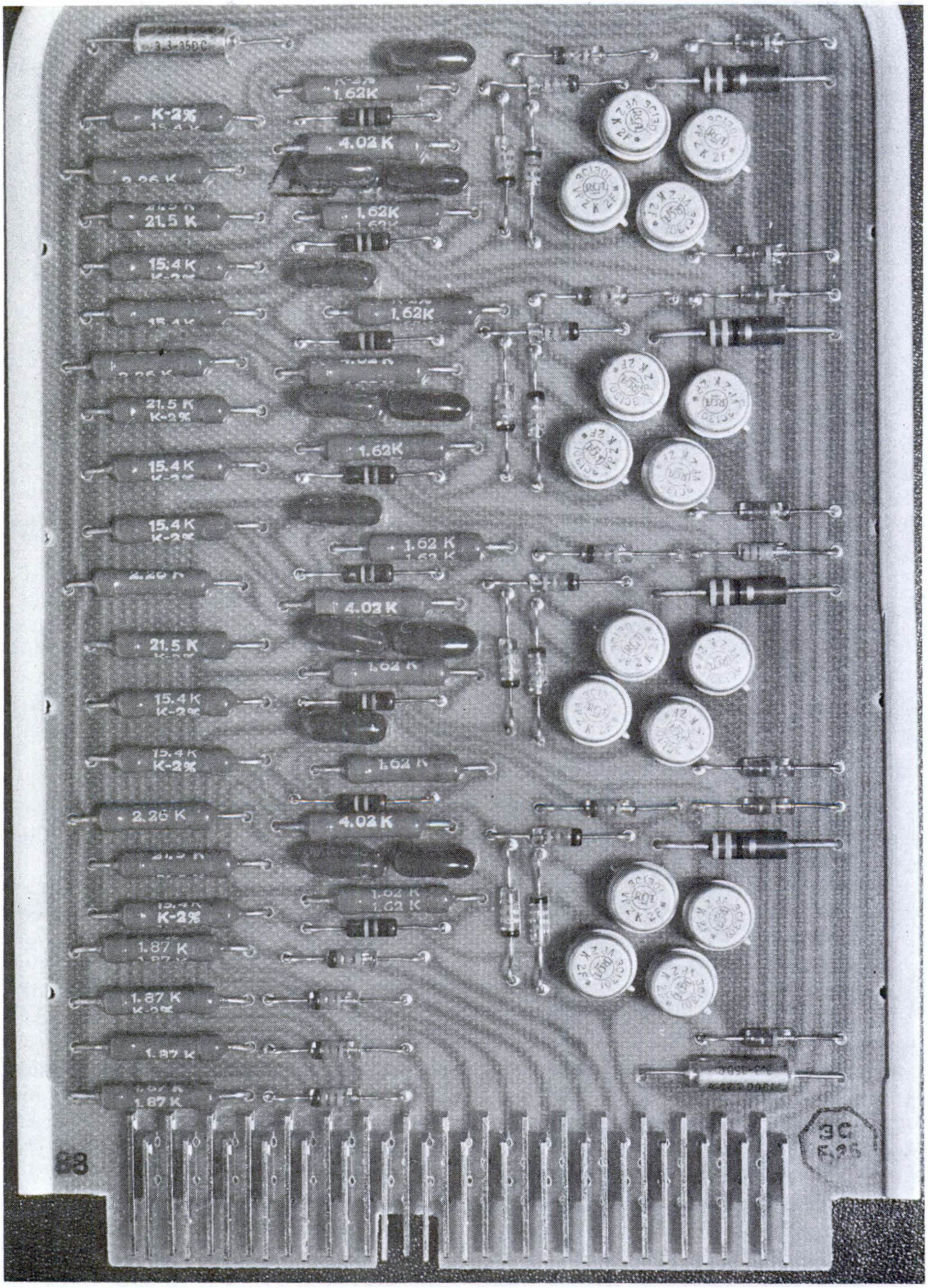

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Figure 18-4.—Electronic module construction.

Repair Technique

The printed circuit presents certain difficulties in soldering techniques that are not common to conventionally wired circuits. Certainly these printed circuits cannot be repaired in a careless manner; but with a little care and commonsense, satisfactory repairs can be made.

Should a printed circuit become broken, it is easily repaired by placing a short length of bare copper wire across the break and soldering both ends to the print; or, if the break is small, simply flow solder across it. (See fig. 18-5.) When performing these operations, do not apply too much heat, and do not permit solder to flow to other printed areas.

The phenolic boards used for printed circuits are similar to the phenolic strips used for conventional terminal strips and mounting boards. There has been no difficulty in soldering to the metal connectors on these terminal strips and mounting boards, so there should be none in soldering printed circuits. In rare cases where excessive heat causes separation of printed conductors from the phenolic board, repairs can be made by using jumper wires. (See fig. 18-6.)

Parts Replacement

In the previous paragraphs the repair of the printed portion of the printed circuit board was discussed. In the following paragraphs, parts such as transistors, resistors, capacitors, etc., which have soldered connections are discussed.

Removal of a part from a printed circuit board without damaging the printed circuit or the associated parts requires that the soldering tool be used with precision and skill.

UNSOLDERING.—When it is necessary to do any unsoldering, the pencil iron and special tips become quite useful. Figure 18-7 (A) illustrates the use of special tips to unsolder multiple terminals. However, it is possible to do the unsoldering with the jury rig illustrated in figure 18-7 (B). A ground lead connected from the tip of the soldering iron to the frame or chassis will prevent damage to transistors and other parts, due to leakage current in the soldering iron. Often it is more convenient, and it is always safer, to completely remove the module and work on it on an insulated surface.

The general procedure recommended for removing soldered parts is applicable to most connections. A chassis holding jig can be used to hold the printed circuit boards. The use of

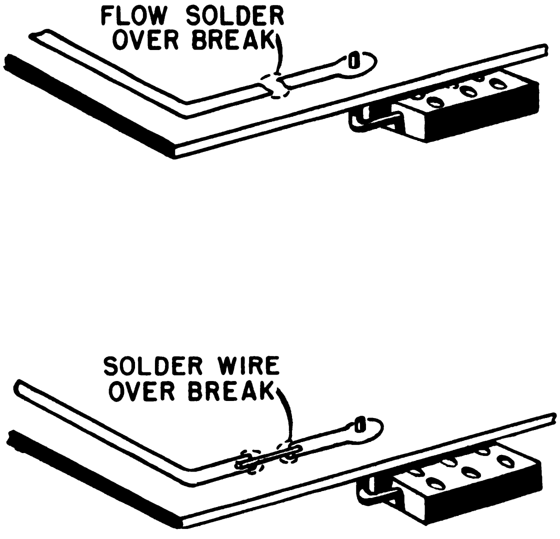

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Figure 18-5.—Repairing breaks in foil.

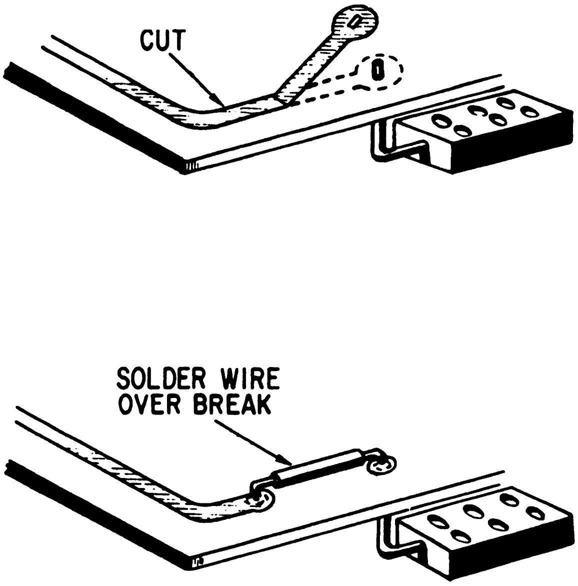

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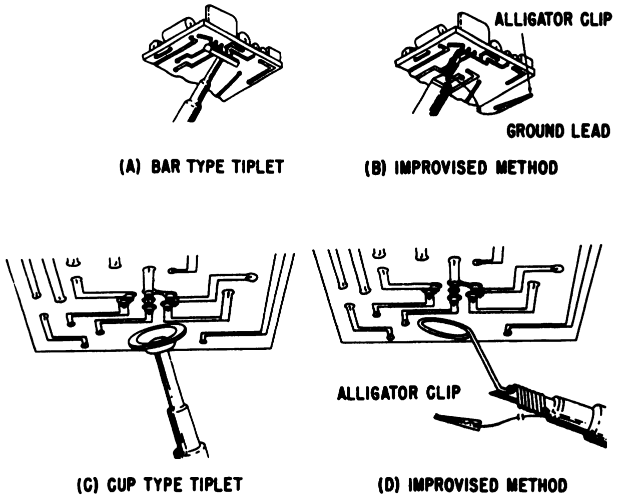
Figure 18-6.—Repairing raised portion of foil.



(A) BAR TYPE TIPLET (B) IMPROVISED METHOD

(C) CUP TYPE TIPLET (D) IMPROVISED METHOD

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Figure 18-7.—Unsoldering multiple terminals.

such a jig allows the worker to make repairs easily and safely.

Position the board in a jig so that the terminals to be unsoldered are facing out and down. Place the tip of a hot pencil soldering iron under and against the terminal. The solder will flow to the soldering tip, and may be removed from the tip by wiping. Remove sufficient solder from each of the terminals to free the part. When the terminals have been loosened, lift the part from the board. The part to be removed should never be pried or forced loose. Any attempt to force a part loose may result in a broken or separated printed circuit panel. If the terminals do not pass easily through their holes, chances are that all the solder has not been removed. Remove any solder left in the terminal hole after removing the leads, by applying the soldering iron to the hole just long enough to soften the solder, and then poke the softened solder out with a toothpick, scribe, or small brush.

Use the special tips whenever possible. If leads, tabs, or small wires are bent against the board or terminal, slotted tiplets may be used to simultaneously melt the solder and straighten the leads.

Parts such as resistors and small capacitors are most conveniently removed if first cut to free their leads. Much less heat is required to remove a part if the leads are free. In cases where it is inconvenient to remove a board for access to the wiring side, it is usually possible to cut the leads of small resistors and capacitors so that a small portion of the lead is exposed. The new part can then be soldered to the old leads. This technique is shown in figure 18-8.

The bar tiplet will remove straight-line multiterminal parts quickly and efficiently, as shown in figure 18-7 (A). The same thing can be done by individually heating each solder connection and brushing away the melted solder.

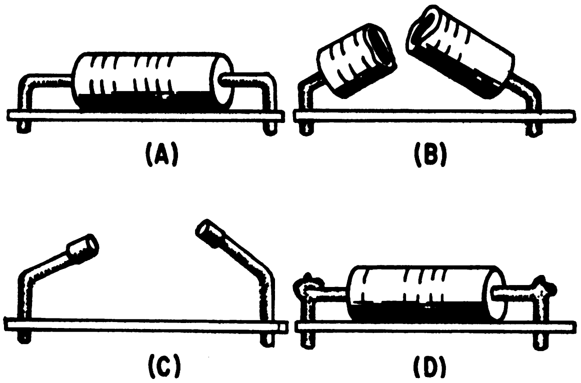

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Figure 18-8.—Replacement of a resistor on a printed circuit.

With the latter method, particular care must be taken so that loose solder does not stick to other parts or the printed panel where it may cause a short. Another way is to improvise a tip to cover all the connections simultaneously, as illustrated in figure 18-7 (B). Care must be exercised to see that this tool contacts only the terminals to be unsoldered—nothing else. Do not allow the tool to remain in contact too long at a time.

The cup tiplet, the triangle tiplet, and the hollow cube tiplet are specially designed to withdraw solder from circular or triangular mounted parts in one operation, as shown in figure 18-7 (C). If these tools are not available, an improvised tip may be used by shaping it to cover the terminals. The same procedures and precautions given for unsoldering straight-line terminals apply here.

Most of the components mounted on a printed circuit board can be removed by the method described. If a problem arises which has not been covered here, spend a little time thinking about the best way to remove the part. The planning you do before tearing into the printed circuit may save you time in the end.

In some cases, excess solder at a printed circuit connection may make removal difficult. The following method may be helpful in such cases: Coat a piece of clean copper braid (such as a ground strap or length of coaxial shield) with a noncorrosive solder flux and apply it to the connection. Heating the braid with a soldering iron will cause the excess solder to transfer to the braid. Be careful not to overheat.

The proper method of solder removal and application is illustrated in figure 18-9 (A), (B), and (C). Part (A) illustrates the correct and incorrect methods of solder application. The correct method for removing solder from a component without damaging the printed wiring circuits is shown in (B). Part (C) shows the correct method for applying solder to a replaced component.

Resistors

When a resistor must be replaced, one of the important considerations in selecting the replacement is the wattage value. In general, the wattage rating is a measure of the ability of the resistor to dissipate heat, and the value is related to the physical size of the resistor.

The selection of a safe wattage value is based on a consideration of the working conditions of

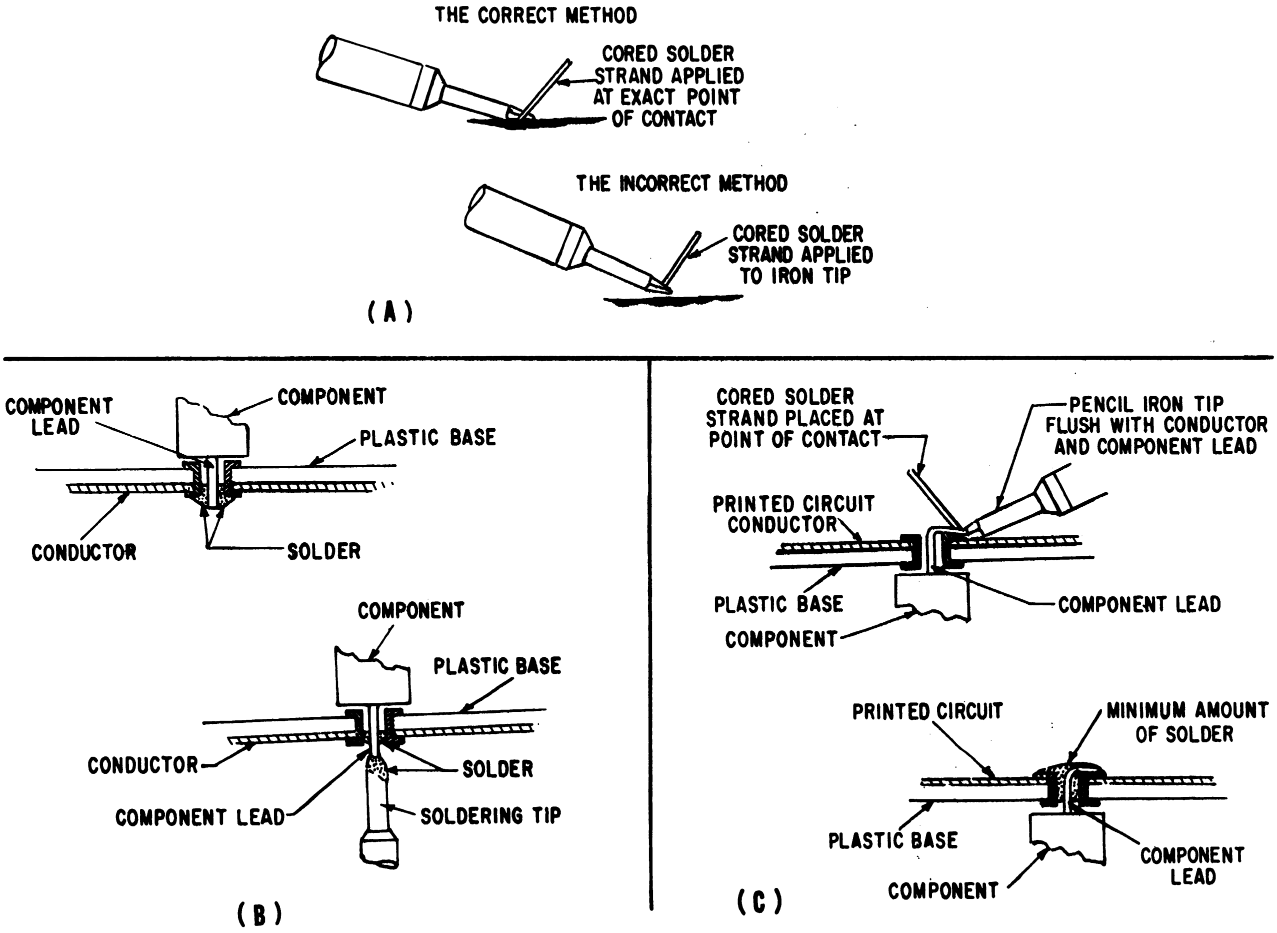

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Figure 18-9.—Soldering techniques.

the resistor in the circuit. Consider as an example the replacement of an 850-ohm resistor with one of equal ohmic value but which has a tolerance of ±20 percent. Suppose the normal voltage existing across the resistor is 40 volts. Because of the 20 percent tolerance, the actual resistance of the replacement may be as much as 1,020 ohms or as little as 680 ohms. Taking the lesser value (the more unfavorable from a heat-dissipating standpoint), the power that may be developed in the resistor under circuit conditions is found as follows:

$$W = \frac{E^2}{R}$$

$$W = \frac{40 \times 40}{680}$$

$$W = 2.35 \text{ watts, approximately}$$

A resistor should be capable of dissipating from 1.5 to 2 times the power actually encountered, to allow sufficient margin of safety. In the example, this value is not more than 4.7 watts. Since a 5-watt resistor is the next standard size above the 4.7-watt value, this is a desirable wattage rating for the replacement.

Under emergency conditions, it is sometimes necessary to combine resistors in series or in parallel to obtain a desired resistance value. When this is done, care should be taken to avoid a voltage distribution (or current distribution) which causes any low-wattage resistor in the combination to dissipate an excessive amount of heat. For example, suppose two 10-watt resistors of 1-ohm value were combined in series with a 2-watt resistor of 10 ohms. The total wattage dissipated when the series combination is connected across 12 volts is 12 watts. But the power dissipated by the 10-ohm, 2-watt resistor is 10 watts, a value far in excess of its capabilities. It is necessary to consider each resistor in the combination and select a wattage value based on the voltage developed across the individual unit.

AIRCRAFT AND EQUIPMENT WIRING

Wiring in aircraft is identified by a system of numbers and letters stamped on each wire. The Maintenance Instructions Manual gives the number of each wire involved in cabling of electronic equipment. Should it become necessary to trace and repair a wire in the aircraft, refer to manual to determine the routing of the wire involved.

Wiring data for all electrical and electronic systems in each model aircraft are contained in the Wiring Data section of the applicable Maintenance Instructions Manual. The diagrams are prepared separately for each circuit and provide all data necessary to understand the construction of each circuit, to trace each circuit within the system, to make continuity and resistance checks, and to perform specific troubleshooting on inoperative or malfunctioning circuits. Schematic diagrams for circuits and related components are found in those volumes of the Maintenance Instructions Manuals specifically covering a system or systems.

CONNECTORS

Connectors are inspected when the major units that they connect are inspected. During this inspection, the mating parts of the connectors are separated and the contacts examined for corrosion. If corrosion is present, the surfaces are cleaned with a brush or clean rag and a noncorrosive solvent. The coupling ring is inspected for battered threads, and should be replaced if the threads are not in good condition. When attaching or detaching the connector, care should be taken to avoid damaging the coupling or bending the coupling nut.

If the connector does not contain a moistureproofing compound, the conductors should be inspected where they are soldered to the pin contacts. Short circuits are often caused by a frayed strand of one conductor touching the solder cup of another conductor within the plug. If this is the case, the frayed strand may be clipped. Check to see that all soldered connections are adequate and that no cold solder joints exist.

Connectors do not require lubrication except for the coupling ring threads. Occasionally, they should be given a light coat of antiseize compound to insure smooth operation.

Maintenance

At times, operating conditions demand that ordinary electrical connectors be given a moistureproofing treatment. The basis of moistureproofing is the application of a sealing compound.

Moistureproofing reduces failure of electrical connectors and reinforces the wires at the connectors against failure caused by vibration and lateral pressure, both of which fatigue the wire at the solder cup.

The sealing compound also protects electric connectors from corrosion and contamination by excluding metallic particles, moisture, and aircraft liquids. As a result of its improved dielectric characteristics, it reduces the possibility of arc-over between pins at the back of electric connectors.

The sealant is provided in kit form through the normal supply channels. Sealing (or potting, as it is called) is not required on environment-proof E connectors or connectors located in areas where the temperature exceeds 200°F. The sealing compound deteriorates after long exposure to ambient temperature above 200°F.

The detailed instructions for performing sealing operations may be obtained from the current Electronic Material Change covering this subject. A summary of the procedures involved in sealing a connector is as follows:

1. Prepare a used connector by removing existing sealants and by cleaning. The cleaning solvent used must clean thoroughly, evaporate quickly, and leave no residue. Remove all sleeving from the wires. Resolder loose or poorly soldered connections and add a length of wire approximately 9 inches long to each unused pin. Remove any excess rosin from around the pins and the insert; a stiff bristle brush is helpful in doing this. Now, repeat the cleaning, and then separate the wires evenly.

2. Thoroughly mix the accelerator and base compound (fig. 18-10). The ratio of the amount of accelerator to the amount of base compound is critical; therefore, the entire quantity of accelerator furnished must be added to the base compound.

3. Place the plugs or receptacles on a table, arranging them so that gravity will draw the sealer to the bottom of the plug. Box receptacles or plugs without back shells must be fitted with a mold made of masking tape or cellophane tape or equivalent. (See (A) of fig. 18-11.) This will retain the sealant during the curing process. If the back shell is used, apply a slight amount of oil to the inner surfaces to prevent the compound from adhering to it.

4. The compound is applied by a spatula, putty knife, or paddle. It should be packed around the base of the pins. The part being potted should be completely filled or at least to a point to cover 3/8 inch of insulated wire. The compound is now allowed to cure; temperature will affect the curing time. The normal curing time is approximately 24 hours.

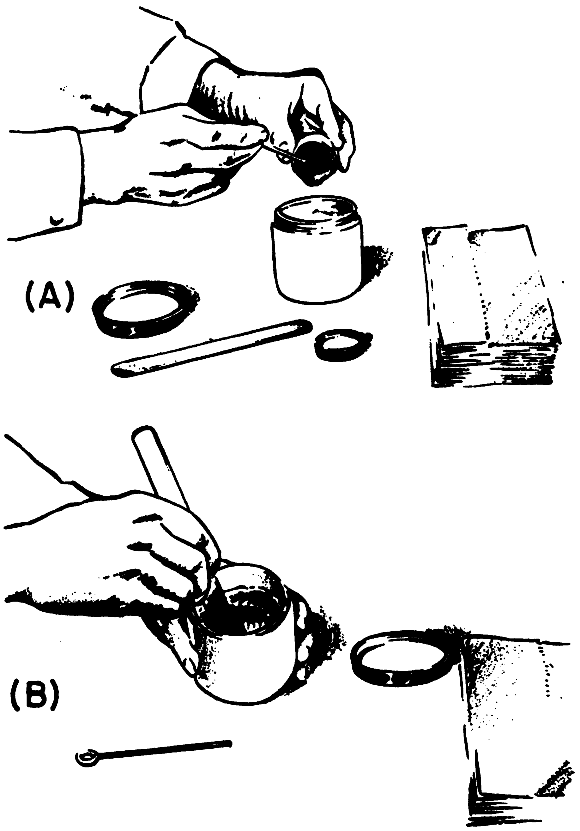

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Figure 18-10.—Combining accelerator with base compound.

If it is desired that the entire connector assembly (plug and receptacle) be sealed against fluid entering or collecting between the two parts, it is necessary that a rubber O-ring be fitted over the barrel of the plug. This will provide a seal when the two parts are engaged securely. If properly installed, this seal will prevent moist air from entering due to variations in temperature, altitude, or barometric pressure on the ground. Rubber packing O-rings are available for this purpose through normal supply channels. Due to the aging of these rings in service, it is necessary to examine them each time the connector is disassembled. If deteriorated, they must be replaced.

The purpose of soldering a short length of wire to each spare pin is to allow for growth

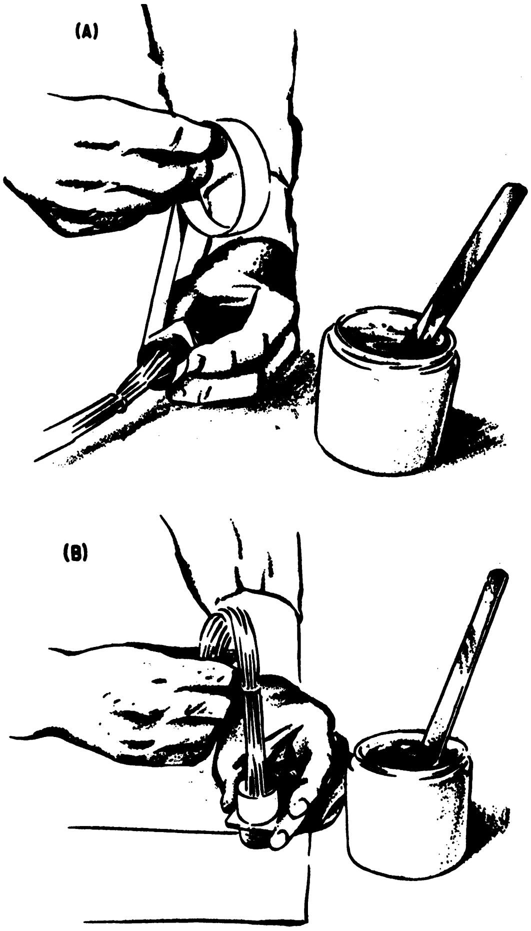

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Figure 18-11.—(A) Making mold from masking tape; (B) finished potted plug.

requiring additional circuits to be included in the connector.

CONDUCTORS AND TERMINALS

Although modern technical literature has been emphasizing the use of printed circuits and microelectronic components in contemporary electronic equipment, conductors are still important as a signal- or current-carrying device. (For the purpose of this discussion the term conductor will refer to both wire and cable.) As a significant part of operating equipment, conductors deserve appropriate attention.

Wire

For wire replacement work, the Maintenance Instructions Manual for the particular aircraft or equipment should first be consulted since it normally lists the wire used. When this information cannot be obtained from the manual, the repairman must select the correct conductor needed for the job. The three major factors involved in this selection in descending order of importance, are size, insulation, and the characteristics required to satisfy specific environments in which the wire must function.

CONDUCTOR SIZE.—For d-c applications, the allowable voltage drop and current-carrying capacity govern the choice of size. At radiofrequencies, the skin effect and inductance may become a controlling factor, although generally (except in inductors or RF transformers) these parameters need not be considered. Wire size is therefore basically a function of the current or the allowable resistance, except when this results in a very small conductor size.

Small conductors are difficult to handle and are subject to breakage in soldering or due to vibration. Experience has shown that these difficulties may be avoided by using No. 22 or No. 24 AWG for general circuit wiring and at least No. 20 AWG for parallel connected tube filaments. Solid wire should be used only for short jumper connections not exceeding 3 inches in length, unless the parts being connected are solidly mounted and not subject to vibration. Clamps or "dress lugs" are recommended for long leads. In other words, the use of stranded copper wire whenever possible is strongly recommended, although under extreme conditions of vibration or where high flexibility is required, oxygen-free copper is sometimes specified. Copperclad steel is another possibility for applications requiring greater strength and rigidity.

INSULATION.—A wide variety of insulating material is available, which makes its specification particularly important. Since each insulation has its peculiar characteristics, no single type is always suitable for general usage. The major insulation requirements include good dielectric strength, high insulation resistance (internal and surface), wide temperature range (with high softening and low brittle points), flexibility, color stability, and resistance to abrasion, crushing, moisture, fungus, burning, radiation, oil, and acids.

Insulation requirements for electronic, as opposed to power, applications are somewhat more exacting due to the higher frequencies and impedances and often higher voltages involved. Insulation resistance and dielectric strength are the prime considerations, although for RF application the figure of merit (capacity to Q ratio) becomes important.

Some of the insulations used for general hookup wire include lacquered cotton, high temperature rubber, butadiene styrene copolymers, Celanese, fiberglass, nylon, vinyl, polyvinylchloride, cellulose acetate, polystyrene, polyethylene, Teflon, and various silicon-treated materials. An insulation wall thickness of not less than 0.013 inch is recommended for all wiring within the confines of an enclosure or where mechanical protection is provided. Where wiring is exposed or subject to wear or abrasion, heavier insulation is required.

ENVIRONMENTS.—Environmental factors such as temperature, humidity, altitude, vibration, radiation, fungus, contaminants, and corrosive elements must be taken into consideration. These requirements are included as a part of the specification for the equipment where the wire is to be used.

Terminals

Since most aircraft wires are stranded, it is necessary to use terminal lugs to hold the strands together and facilitate fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified on the electrical wiring diagram for the particular models. Soldered and crimped type terminals may be used interchangeably, but both must have the same amperage capacity and the same size hole in the lug.

The increased use of crimp-on terminals is based to a large degree upon the limitations of soldered terminals. The quality of soldered connections depends mainly upon the operator's skill. Such factors as temperature, flux, cleanliness, oxides, and insulation damage due to heat also contribute to defective connections when they are not precisely controlled.

The crimp-on solderless terminals require relatively little operator skill. Another advantage is that the use of a crimping tool eliminates the necessity of supplying power to a soldering iron. This allows terminals to be applied in an aircraft with a minimum of time and effort. The connections are made more rapidly, are cleaner, and are more uniform. Due to the pressures exerted and the materials used, the crimped connection or splice, properly made, has an electrical resistance that is less than that of an equivalent length of wire.

The basic types of terminals are shown in figure 18-12. Part (A) shows the straight type, (B) the right angle type, (C) the flag type, and (D) the splice type. There are also variations of these types, such as the use of a slot instead of a terminal hole, three- and four-way splice type connectors, and others.

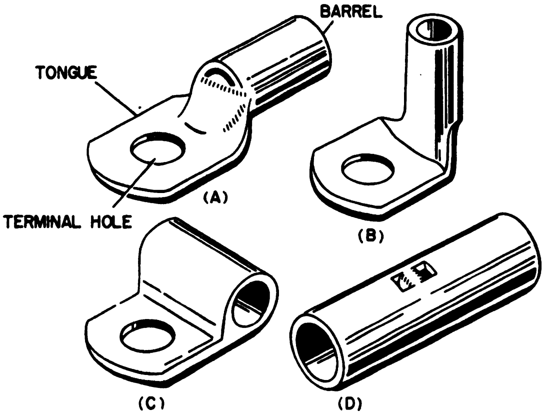

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Figure 18-12.—Types of solderless terminals.

Since both copper and aluminum wiring is used in present-day aircraft, both copper and aluminum terminals are necessary. Various size terminal or stud holes will be found for each of the different wire sizes. A further refinement of the solderless terminals is the insulated type; the barrel of the terminal (fig. 18-12) is enclosed in an insulation material. The insulation is compressed along with the terminal barrel when crimping, but is not damaged in the process. This eliminates the necessity of taping or tying an insulating sleeve over the joint.

Cable Splicing

A cable splice, other than one made with the crimp-on splice or connector, is employed as an emergency measure only. Solder may or may not be used, as the condition warrants, but in any case the splice should give a good electrical and mechanical joint without solder. The splice should be taped to give insulation equivalent to the rest of the cable. A permanent repair must be made as soon as possible.

Consult section XII of Engineering Handbook Series for Aircraft Repair, Aircraft Structural Hardware (AN 01-1A-8), and/or Installation Practices for Aircraft Electrical and Electronic Wiring, NW 01-1A-505, for detailed information dealing with attaching cable terminals, forming terminals for emergency use, and repairing damaged or broken cables.

Terminal Blocks and Junction Boxes

Terminal blocks are made from an insulating material which supports and insulates a series of terminals from each other as well as from ground. They provide a means of installing terminals within junction boxes and distribution panels.

Two methods of attaching cable terminals to terminal blocks are illustrated in figure 18-13. In (A) of the figure a standard nonlocking nut is used. In this method of installation, the use of a lockwasher is necessary. The preferred method is shown in (B) of the figure. An anchor nut, or self-locking nut, is used and the lockwasher is retained for additional security. The use of anchor nuts is especially desirable in areas of high vibration. In both installations, it is required that a flat washer be employed, as shown in the drawing.

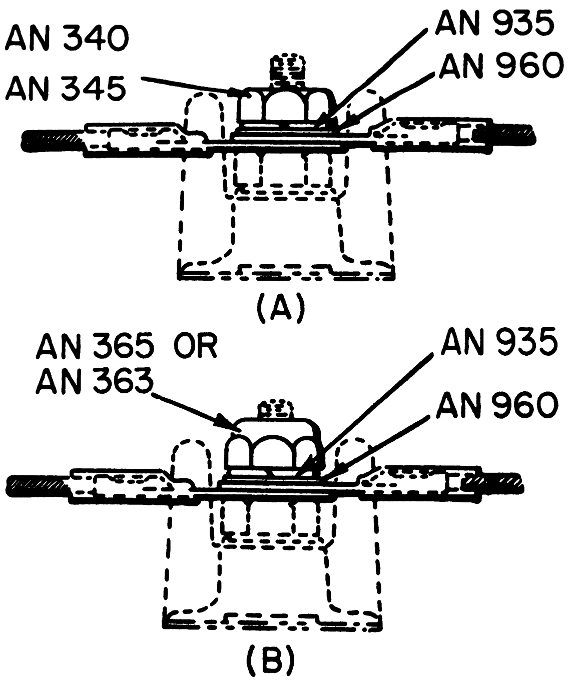

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Figure 18-13.—Installation of cable terminals on terminal block.

Junction boxes are installed to accommodate electrical terminals or other equipment, such as relays and transformers. Individual junction boxes are named according to their function, location, or equipment with which they are associated. Junction boxes are usually provided with a drain hole (except boxes labeled "vapor-tight") located at the lowest point so that water, oil, condensate, or other liquids will not be trapped.

Insulating Sleeving

Insulating sleeving (commonly called "spaghetti") is used in electronic maintenance operations in many aviation activities. Among the operations involving use of the sleeving are the fabrication of cable connectors, connection to relays and terminal strips, crimped or soldered terminal lugs or splices, tie points on terminal strips or terminal boards, etc.

Support Clamps

Clamps are used to provide support for open wiring, and to serve instead of (or in addition to) lacing on open wiring. They are usually supplied with a rubber cushion. When used with shielded conduit, the clamps are of the bonded type (fig. 18-14 (A)); that is, provision is made for electrical contact between the clamp and

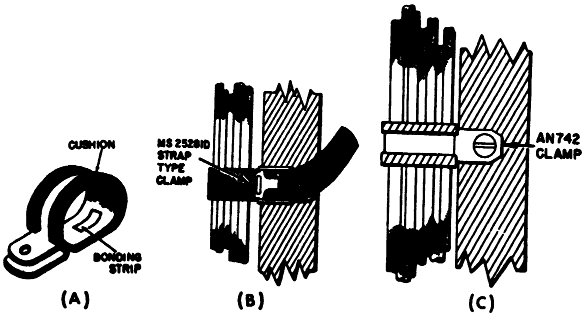

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Figure 18-14.—Cable clamps.

conduit. Unbonded clips are used for the support of open wiring.

Long runs of cable between panels are supported either by a strap type clamp, shown in (B) of figure 18-14, or by a clamp of the type shown in (C) of the same figure. The preferred method of supporting cables for all types of runs is with the type shown in (C). When the strap type clamps are used, precautions must be exercised to insure that they will hold the cables firmly away from lines, surface control cables, pulleys, and all movable parts of the aircraft; these clamps should be used only as an emergency measure.

When cables pass through lightening holes, the installation should conform to the examples shown in figure 18-15. The cable should be routed clear of the edges of the lightening hole, to avoid any possibility of chafing of the insulation.

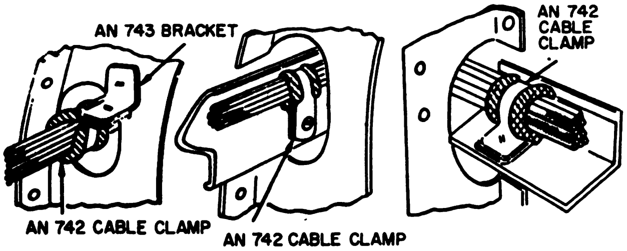

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Figure 18-15.—Routing cables through lightening holes.

Replacement of Wiring

When installing or replacing wire or wire bundles, care should be exercised to insure that there is not excessive slack between cable clamps. Normally, slack should not exceed 1/2 inch deflection with normal hand pressure. A sufficient amount of slack should be allowed at each end to permit the following:

1. Easy removal and connection of plugs.
2. Replacement of terminals two times.
3. Prevent mechanical strain on the wires.
4. Permit free movement of shock and vibration-mounted equipment.
5. Shifting of equipment for maintenance.

Bends in individual wires should normally be kept to a minimum bend radius of 10 times the diameter of the bundles. However, where the wire is suitably supported at each end of the bend, a minimum bend radius of 3 times the diameter of the bundles is acceptable.

Never bend coaxial cable to a radius smaller than 6 times its outside diameter, as damage to the cable will result. Coaxial cables should be routed as directly as possible, avoiding any unnecessary bends.

Wires passing through a bulkhead must be supported at each hole by a cable clamp. If the clearance between the wires and the edge of the hole is less than 1/4 inch, use a suitable grommet in the hole. (See fig. 18-16.)

Maintain a minimum clearance of 3 inches between wiring and control cables. If this cannot be done, install guards to prevent contact of the wiring with the control cables. When the wiring must be routed parallel to plumbing carrying flammable fluids or oxygen, maintain as much separation as possible. Support the wiring so it cannot come closer than 1/2 inch to the plumbing. Never support any wire or

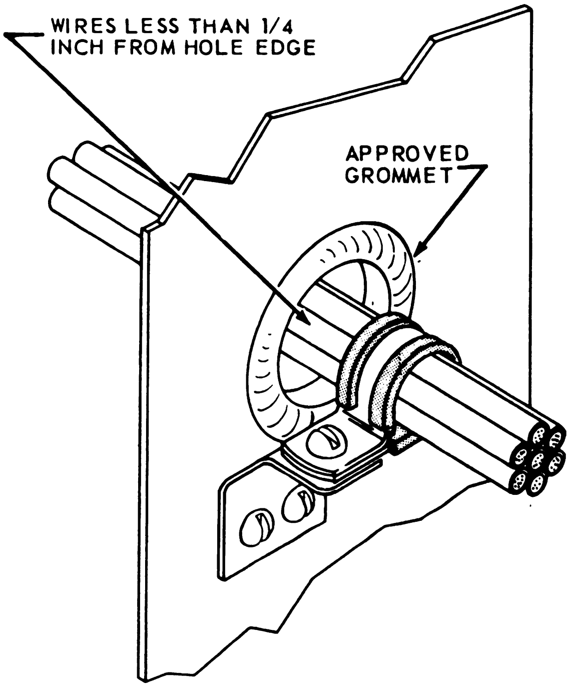

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Figure 18-16.—Cable clamp and grommet at bulkhead hole.

wire bundle from a plumbing line carrying combustible liquids or oxygen.

Cable clamps should be installed so that the mounting screws are above the wire bundle. (See fig. 18-17.) Otherwise the weight of the cable may bend and break the clamp. It is also desirable that the back of the clamp rests against a structural member if practicable. Be careful not to pinch wires in the cable clamp.

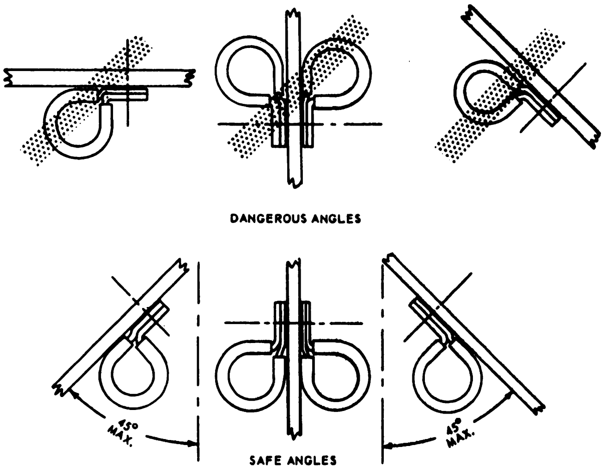

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Figure 18-17.—Safe angles for cable clamps.

LACING AND TYING.—Wire groups and bundles are laced or tied with cord to provide ease of installation, maintenance, and inspection. It keeps the cables neatly secured in groups and bundles to help avoid possible damage from chafing or equipment operation.

Tying is the securing together of a group or bundle of wires by means of individual pieces of cord ties around the group or bundle at regular intervals.

Lacing is the securing together of a group or bundle of wires inside enclosures, by means of a continuous piece of cord, forming loops at regular intervals around the group or bundle. A wire group is two or more wires tied or laced together to give identity to an individual system. A wire bundle is two or more wires or groups tied or laced together to facilitate maintenance.

Use cotton, nylon, or fiberglass cord for lacing or tying. Cotton cord must have been waxed to make it moisture and fungus resisting. Nylon and fiberglass cords are in themselves moisture and fungus resisting, and are not usually waxed. Use pressure sensitive vinyl electrical tape only where the use of tape instead of cord is specifically permitted.

When lacing or tying, observe the following precautions:

1. Lace or tie bundles tightly enough to prevent slipping, but not so tight that the cord cuts into or deforms the insulation. This applies especially to coaxial cable, which has a soft dielectric insulation between the inner and outer conductor.
2. Do not place ties on that part of a wire group or bundle that is located inside a conduit.
3. Lace wire groups or bundles only inside enclosures, such as junction boxes. Use double cord on groups or bundles larger than 1 inch in diameter. Use single or double cord for groups or bundles 1 inch or less in diameter.

NOTE: Coaxial cables have been damaged by the use of lacing materials or by methods of lacing or tying wire bundles which cause a concentrated force on the cable insulation. Elastic lacing materials, small diameter lacing cord, and excessive tightening deform the interconductor insulation and result in short circuits or impedance changes. Avionics Bulletin No. 8 of May 1963 directs the use of the flat nylon braided waxed lacing tape (FSN 4020-730-2622-L980) for lacing or tying any wire bundles which include coaxial cables.

Lace a wire group or bundle with a single cord as follows:

1. Start the lacing at the thick end of the wire group or bundle with a knot consisting of a clove hitch with an extra loop. (See fig. 18-18.)

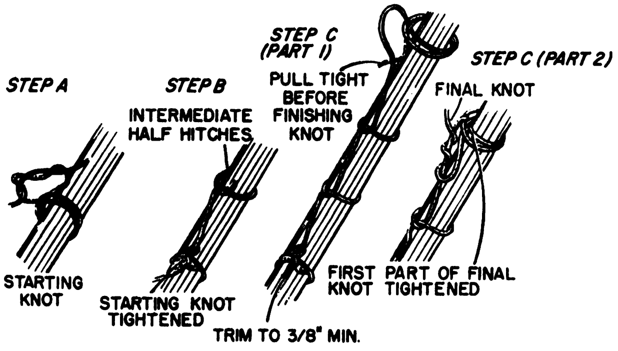

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Figure 18-18.—Single cord lacing.

2. At regular intervals along the wire group or bundle, and at each point where a wire or wire group branches off, continue the lacing with half hitches. Space half hitches so that the group or bundle is neat and securely held.
3. End the lacing with a knot consisting of a clove hitch with an extra loop.
4. Trim the free ends of the lacing cord to 3/8 inch minimum.

Lace a wire group or bundle with a double cord as follows:

1. Start the lacing at the thick end of the wire group or bundle with a bowline on a bight. (See fig. 18-19.)
2. At regular intervals along the wire group or bundle, and at each point where a wire group branches off, continue the lacing with half hitches, holding both cords together. Space half hitches so that the group or bundle is neat and securely held.
3. End the lacing with a knot consisting of a half hitch, using one cord clockwise and the other counterclockwise, and then tying the cord ends with a square knot.
4. Trim the free ends of the lacing cord to 3/8 inch minimum.

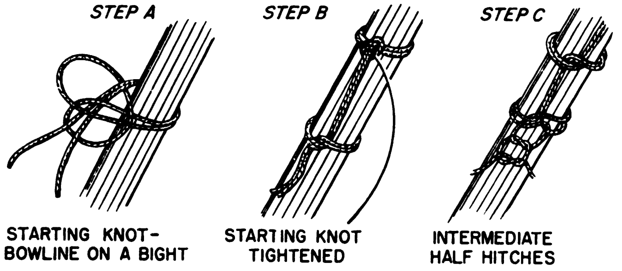

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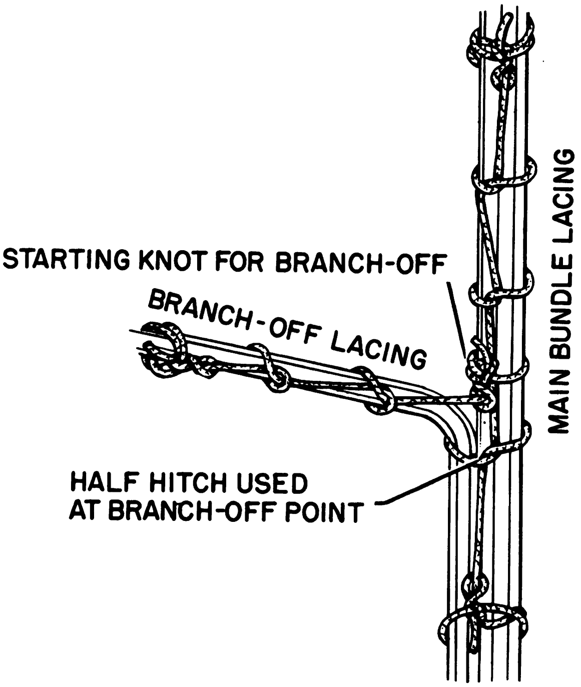
Figure 18-19.—Double cord lacing.

Lace a wire group that branches off the main wire bundle as follows:

1. Start the branch-off lacing with a starting knot (fig. 18-20) located on the main bundle just past the branch-off point. When single cord lacing is used, make this starting knot the same as for regular single cord lacing. When double cord lacing is used, use the double cord lacing starting knot.


STARTING KNOT FOR BRANCH-OFF
BRANCH-OFF LACING
MAIN BUNDLE LACING
HALF HITCH USED AT BRANCH-OFF POINT

AQ.614

Figure 18-20.—Lacing a branch-off.

2. End the lacing with the regular knot used in single and double cord lacing, as previously described.
3. Trim the free ends of the lacing cord to 3/8 inch minimum.

Tie all wire groups or bundles where supports are more than 12 inches apart. Space ties 12 inches or less apart.

Make a tie as follows:

1. Wrap cord around wire group or bundle, as shown in (A) of figure 18-21.
2. Make a clove hitch, followed by a square knot with an extra loop.
3. Trim free ends of cord to 3/8 inch minimum.

When tying sleeves to wire groups or wire bundles, the ties are made the same as for wire groups and bundles.

When it is permissible to use tape, the following method should be employed:

1. Wrap tape around the wire group or bundle three times, with a two-thirds overlap for each turn. (See (B) of fig. 18-21.)
2. Heat-seal the loose tape end with the side of a soldering iron heating element. Do not use

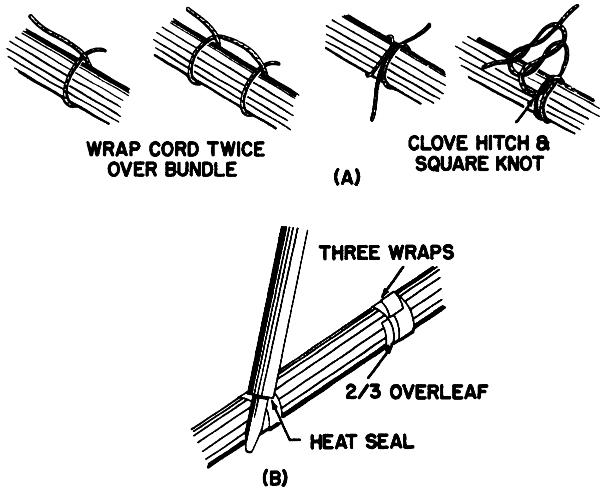


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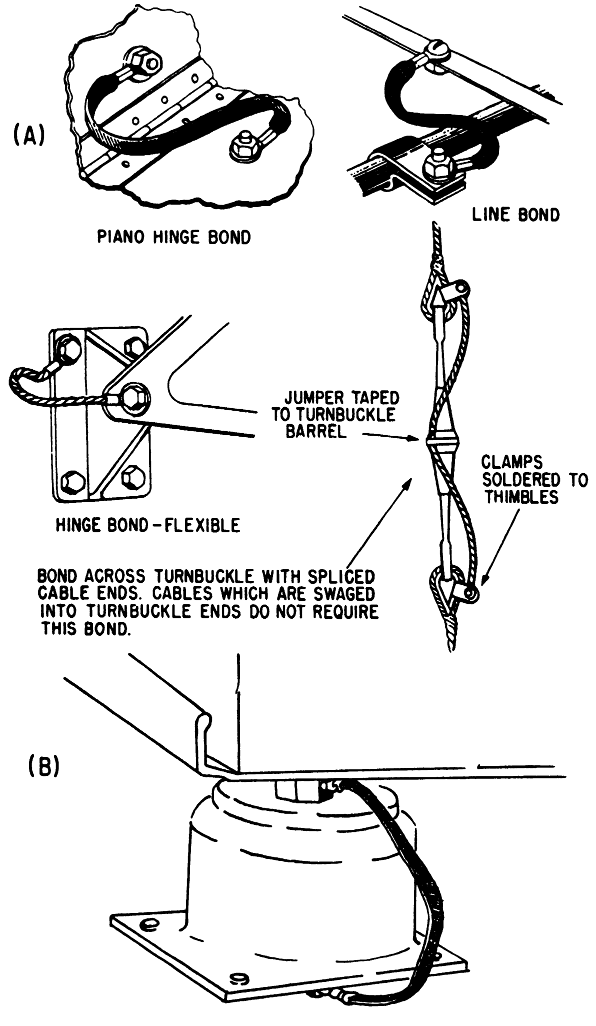
Figure 18-21.—Tying groups or bundles.

tape for securing wire groups or bundles which may require frequent maintenance.

BONDING

A bond is any fixed union existing between two metallic objects that results in electrical conductivity between them. Such a union results either from physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them. Aircraft electrical bonding is the process of obtaining the necessary electrical conductivity between the component metallic parts of the aircraft. An isolated conducting part of an object is one that is physically separated by intervening insulation from the aircraft structure and from other conductors which are bonded to the structure.

A bonding connector provides the necessary electrical conductivity between metallic parts in an aircraft not in sufficient electrical contact. Examples of bonding connectors are bonding jumpers and bonding clamps. (See fig. 18-22.)


(A)
PIANO HINGE BOND
LINE BOND
JUMPER TAPED TO TURNBUCKLE BARREL
CLAMPS SOLDERED TO THIMBLES
HINGE BOND-FLEXIBLE
BOND ACROSS TURNBUCKLE WITH SPLICED CABLE ENDS. CABLES WHICH ARE SWAGED INTO TURNBUCKLE ENDS DO NOT REQUIRE THIS BOND.
(B)

AT.272

Figure 18-22.—Bonding methods.

An aircraft can become highly charged with static electricity while in flight. If the aircraft is improperly bonded, all metal parts will not have the same amount of charge. A difference of potential will then exist between various metal surfaces. The neutralization of the charges flowing in paths of variable resistance, due to such causes as intermittent contact from vibration or the movement of the control surface, will produce electrical disturbances (noise) in the radio receiver. If the resistance between isolated metal surfaces is great enough, charges can accumulate until the potential difference becomes sufficiently high to cause a spark. In addition to creating radio interference, this also constitutes a fire hazard. In the case of lightning striking the aircraft, a good conducting path is necessary for the heavy current in order to minimize severe arcs and sparks which would damage the aircraft and possibly injure its occupants.

The aircraft structure is also the ground for the radio. For the radio to function properly, a proper balance must be maintained between the aircraft structure and antenna. This means the surface area of the ground must be constant. Control surfaces, for example, may at times become partially insulated from the remaining structure due to a film of lubricant on the hinges. This would affect radio operation if the condition were not taken care of by bonding.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance return path also aids the effectiveness of the shielding, and provides a means of bringing the entire aircraft to the earth's potential when it is grounded.

The reason for bonding may be summed up as follows:

1. To minimize radio and radar interferences by equalizing static charges that accumulate.
2. To eliminate a fire hazard by preventing static charges from accumulating between two isolated members and creating a spark.
3. To minimize lightning damage to the aircraft and its occupants.
4. To provide the proper ground for proper functioning of the aircraft radio.
5. To provide a low-resistance return path for single-wire electrical systems.
6. To aid in the effectiveness of the shielding.
7. To provide a means of bringing the entire aircraft to the earth's potential and keeping it that way while it is grounded to the earth.

Bonding connection should be installed so that vibration, expansion or contraction, or relative movement incident to normal service use will not break the bonding connections or loosen them to such an extent that the resistance will vary during the movement. The bonding of most concern will be the bonding jumpers that are placed across shock mounts, which are used to support electronic equipment.

Since a primary objective for bonding is to provide an electrical path of low d-c resistance and low RF impedance, it is important that the jumper be a good conductor of ample size for the current-carrying capacity, have low resistance, and be as short as possible. Insofar as practical, parts should be bonded directly to the basic aircraft structure rather than through other bonded parts. Bonding jumpers should be installed in a manner so as not to interfere in any way with the operation of movable components of the aircraft.

Contact of dissimilar metals in the presence of an electrolyte, such as salt water, produces an electric action (battery action) which causes a pitting in one of the metals. The intensity of this electric action varies with the kinds of metals. Bonding frequently necessitates the direct contact of dissimilar metals. In such cases the metals used are of the kind that will produce a minimum of corrosion. The connections are also made so that if corrosion does occur, it will be in replaceable elements, such as jumpers, washers, or separators, rather than in the bonded or bonding members. Thus, washers made of the same material as the structural member should be used against the structural member, and washers of the same material as the bonded member should be in contact with that item.

Self-tapping screws should not be used for bonding purposes nor should jumpers be compression-fastened through plywood or other nonmetallic material. When performing a bonding operation, the contact surfaces should be cleaned of insulating finishes or surface films before assembly, and then the completed assembly refinished with a suitable protective finish.

Consult Installation Practices for Aircraft Electric and Electronic Wiring, NW 01-1A-505, for more detailed information dealing with bonding.

SHOCK MOUNTS

Electronic equipment is sensitive to mechanical shock and vibration; therefore, units of electronic equipment are normally shock mounted to provide some protection against inflight vibration and against launching and landing shock. The specific type shock mount is prescribed in the Maintenance Instructions Manual for the specific aircraft, and substitution should not be made.

Periodic inspection of shock mounts is required, and defective mounts should be replaced with the prescribed type. In the inspection, the main factors are chemical deterioration of the shock absorbing material, stiffness and resiliency of the material, and overall rigidity of the mount. If the mount is too stiff or too rigid, it may not provide adequate protection against the shock of launching and landing; if it is not stiff or rigid enough, it may permit prolonged vibration following an initial shock. When determining the limits of rigidity and resiliency, consideration must be given to the weight of the mounted unit as well as the amounts of positive and negative acceleration to which it is subjected.

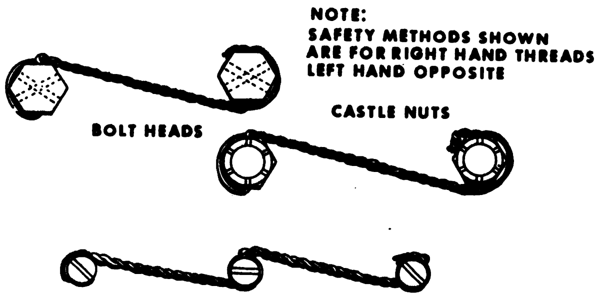
Shock absorbing materials commonly used in shock mounts are usually electrical insulators. For the sake of safety, it is required that each electronic unit mounted in this manner must be electrically bonded to a structural member of the aircraft. (See fig. 18-22 (B).) The bonding strap should also be included in the inspection of the shock mounts, and defective or ineffective bonds should be replaced or reinstalled.

SAFETY WIRING

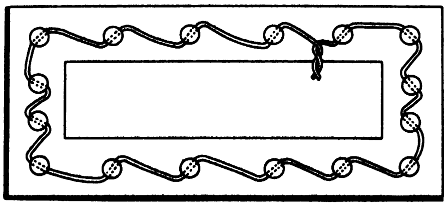
Some equipment parts require a positive safety locking device. The use of safety wire is one accepted method of providing this safety measure. The two most common applications of safety wire are the tying together of nuts, bolts, screws, and connector parts to prevent them from coming loose due to aircraft vibration, and to prevent a guarded switch from being accidentally engaged. In the following paragraphs some of the methods of applying safety wire are discussed.

The most common method of safetying nuts, bolts, and screws is known as the double-twist method. The twisting may be accomplished by hand, or the special safety wire pliers may be used. (See fig. 18-23 (A).) If the twists are made by hand, the final few twists should be made with pliers in order to apply tension and secure the ends of the wire properly. The safety wire should always be installed and twisted so that the loop around the head stays down and does not tend to come up over the bolthead, causing a slack loop. Extreme care must be used when twisting the wires together to insure that they are tight but not overstressed to the point where breakage will occur under a slight load or vibration. Always use new safety wire on every job and take care to use pliers only on the ends of the wire so as not to nick the wire. If safety wire becomes nicked, discard it and use a new piece. When the final twists are made with pliers, cut off the loose ends that have been nicked by the pliers and bend the end of the wire around the bolt or screw head to protect personnel from the sharp ends.

The single wire method of safety wiring (fig. 18-23 (B)) may be used on small screws in a closely spaced area provided the screws form a closed geometrical pattern. Note that any loosening tendencies will pull against the tension of the wire. Never "back off" or overtorque in order to aline holes for safety wiring.


NOTE:
SAFETY METHODS SHOWN ARE FOR RIGHT HAND THREADS LEFT HAND OPPOSITE
CASTLE NUTS
BOLT HEADS

SCREW HEADS
DOUBLE-TWIST METHOD
(A)



SMALL SCREWS IN CLOSELY SPACED
CLOSED GEOMETRICAL PATTERN
SINGLE WIRE METHOD
(B)

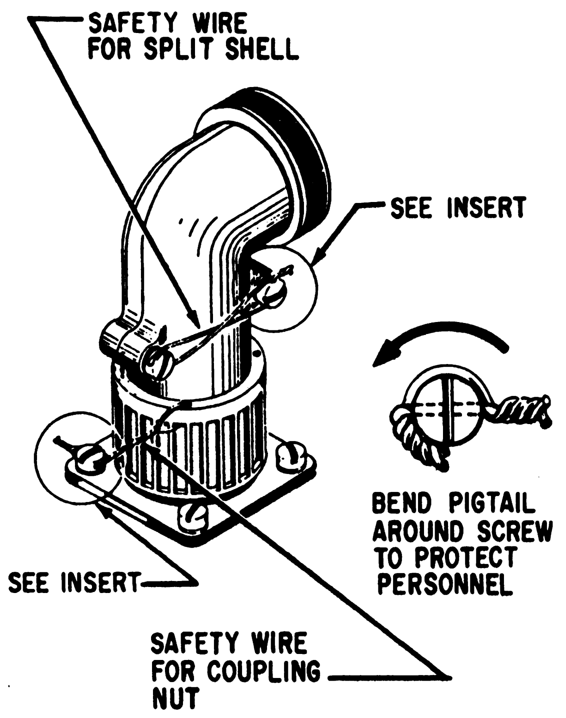
AQ.615

Figure 18-23.—Safety wiring nuts, bolts, and screws.

Safety wire electric connectors only when specified on engineering drawings or when experience has shown the connector will not stay tight. Electric connectors are usually safety wired in engine nacelles, areas of high vibration, and in locations not readily accessible for periodic maintenance inspection.

When it is necessary to safety wire electrical connectors, use 0.032-inch diameter wherever possible. On small parts with holes 0.045-inch nominal diameter or smaller, use 0.020-inch diameter safety wire. If the connector to be safety wired does not have a wire hole, remove the coupling nut and drill a No. 56 (0.046-inch diameter) hole diagonally through the edge of the nut. Figure 18-24 shows a properly safety wired connector.

An example of safety wiring a guarded switch is illustrated in figure 18-25. Note that the wire is not twisted tightly. Very soft wire is used; the wire may be either aluminum or copper. This soft wire allows the operator to easily break the wire when it is necessary to engage the switch.


SAFETY WIRE FOR SPLIT SHELL
SEE INSERT
BEND PIGTAIL AROUND SCREW TO PROTECT PERSONNEL
SEE INSERT
SAFETY WIRE FOR COUPLING NUT

AQ.616
Figure 18-24.—Safety wiring a connector.

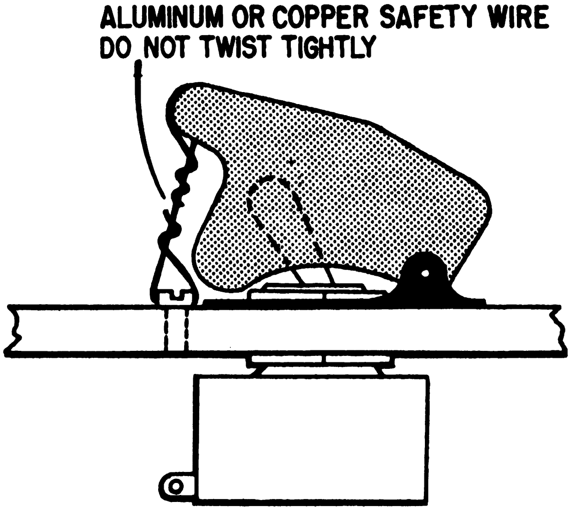
ENVIRONMENTAL PROBLEMS

Although the need for reliability in military avionics equipment has remained relatively constant since the start of World War II, the difficulty of attaining this reliability has increased. The continually increasing complexity of avionics equipment and the subjection of equipment to more and more rigorous environmental conditions are among the chief causes of equipment failure. For these reasons the technician should understand the effects of environmental conditions on the equipments and the design techniques used to minimize these effects.

The environmental factors that should be understood in order to maintain the design characteristics include temperature, humidity, pressure, and abrasive conditions.

TEMPERATURE

Extensive research has been conducted to develop external component parts that are better



AQ.617
Figure 18-25.—Safety wire on a switch guard.

able to withstand operation under extreme temperatures. Extremely low temperatures cause brittleness in metal and loss of flexibility of rubber, insulation, and similar materials. Extremely high temperatures may cause deformity and deterioration of these items. Most internal component parts are not able to withstand these extreme temperatures.

Because equipment is normally installed in confined spaces aboard aircraft, the generated heat causes the temperature to rise; therefore, many units have fans installed to increase the air circulation, thus reducing the temperature within the unit. Most of the new models of aircraft utilize the electronic equipment compartment concept, and use blast air from outside the aircraft or from the aircraft's air-conditioning system for cooling.

HUMIDITY

Humidity, a measure of water content in the air, is a possible cause of avionic equipment or component failure. High humidity (that is, a high water content in the air) provides a possible environment for corrosion and fungus growth. A high moisture content in the air may cause short circuiting between points of high potential.

In certain cases the removal of heat from equipment requires the use of external air. If this external air has a high moisture content, the cooling may be accomplished by one of two ways. First, the high humidity air may be directed through an air jacket which surrounds the equipment. In this case the heat is removed without allowing the humid air to come in contact with the internal equipment components. Second, when the internal equipment components require direct air for heat removal, the direct air is passed through silica-gel crystals, removing the moisture from the air. It should be apparent that the second method is less troublesome because the first case does cause corrosion within the air jacket.

PRESSURIZATION

When high voltage electrical equipment is operated at high altitudes, there is always the problem of arcing. This is caused by the reduced dielectric strength of the air as it becomes thinner. To reduce the possibility of arcing, the case of the equipment is pressurized. Thus, all components inside the case are subject to pressurization, and the possibility of arcing is minimized. In the case of radar operation at high altitudes, the waveguides and parts of the antenna are also pressurized.

Pressurization is usually not a big maintenance problem, but on occasions will cause trouble. The troubles that do arise in the pressurization system are usually the result of poor preventive maintenance. To have a trouble-free pressure system, all seals and gaskets (located at the points of separation, waveguide joints, and case covers) must be very carefully installed to provide an airtight seal. When pressurization troubles do occur, they may be difficult to detect since a very small leak is normally all it takes to render the system inoperable. Before attempting to put the system under pressure for checking for leakage, first consult the Maintenance Instructions Manual. This is necessary since each system has certain specifications concerning the amount of pressure that may be safely applied. If excessive pressure is applied, it could possibly rupture the seals or gaskets, or even cause mechanical damage to parts of the equipment.

ABRASIVE CONDITIONS

Sand, dust, and other substances which are abrasive in nature affect many components. Generally these components are parts that are not sealed off from the atmospheric conditions. In some cases the abrasive material is formed even though the unit is sealed. Examples are generators, motors, and dynamotors which use brushes. Also the protective coating may be removed from a part by the movement of the abrasive material in the air that is used for cooling. This may allow the unprotected metal to corrode.

Modern aircraft configurations employ the use of air-conditioning systems for the purpose of cooling the avionics equipments. The external air is used to cool the heat exchanger while the internal air used to remove heat from the equipment may be pressurized. The use of the pressurized air for equipment heat removal minimizes the undesired environmental effects of temperature, humidity, arc-over, and abrasive conditions.

SHOCK, VIBRATION, AND ACCELERATION

Since acceleration effects are directly related to mass, the smaller the object, the less the mass and inertia, all other factors being equal. The extended use of miniaturization and printed circuits will, to some extent, counteract the troubles due to increased accelerations and shocks that military electronic equipments are now encountering.

Vibration effects are directly related to the resonant mechanical frequency of the equipment. A reduction of shock and vibration effects may be obtained by locating the heavier components as close as possible to the mounting points, to reduce the length of the moment arm.

The decision concerning whether to mount entire equipments on shock and vibration mounts or to mount each component individually should be based upon the overall mass. Using vibration mounts for components and then mounting the entire chassis on shock mounts would probably result in amplification of vibration.

CORROSION CONTROL

In modern aircraft, the need for corrosion control has become a major concern in the availability and maintenance of our striking forces. This is because corrosion is something that destroys equipment and is active 24 hours a day. It is of the utmost importance that its nature be understood in order to combat corrosion.

NATURE OF CORROSION

Metal corrosion is the deterioration of metals as they combine with oxygen to form metallic oxides. This combining is a chemical process which is essentially the reverse of the process of smelting the metals from their ores. Very few metals occur in nature in the pure state. For the most part, they occur naturally as metallic oxides. These oxides may be also mixed with other undesirable impurities in the ores. The refining processes generally involve the extraction of relatively pure metal from its ore and the addition of other elements (either metallic or nonmetallic) to form alloys. Alloying constituents are added to base metals to develop a variety of useful properties. For example, in aircraft structural applications, high strength-to-weight ratios are the most desirable properties in all alloys.

After refining, regardless of whether or not alloyed, base metals possess a potential or tendency to return to their natural state. However, potential is not sufficient in itself to initiate and promote this reversion. There must also exist a corrosive environment in which the significant element is oxygen. It is this process of oxidation—combining with oxygen—that causes wood to rot or burn and metals to corrode. This corrosion is usually referred to as chemical corrosion.

Electrochemical Corrosion

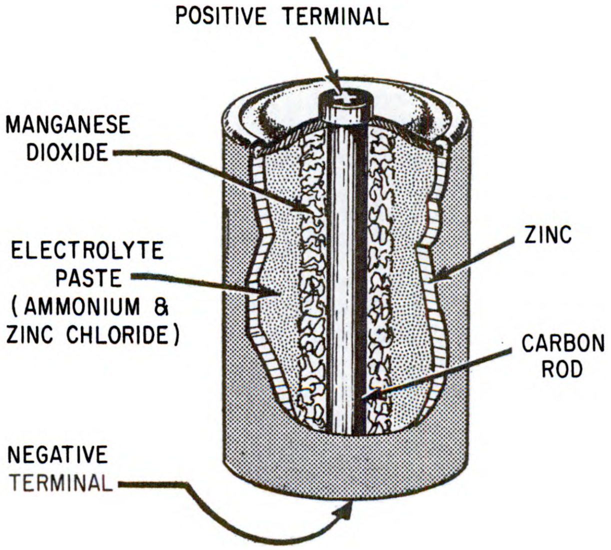
While chemical corrosion is generally readily apparent, electrochemical corrosion is insidious in its destruction. Electrochemical corrosion includes galvanic or dissimilar metals corrosion. This type of corrosion is caused by an exchange of electrons between two metallic areas of different activity (potential) by way of an electrolyte. Three conditions must be present in order for electrochemical corrosion to take place. The first condition is that two or more areas of metal are needed to act as electrodes. The second condition is the requirement of the presence of an electromotive force. The last requirement is the presence of an electrolyte to complete the formation of a cell.

It is not necessary to know all the theories concerning electrochemical corrosion, but a brief understanding of the deterioration of metals will be beneficial in combating this type of corrosion.

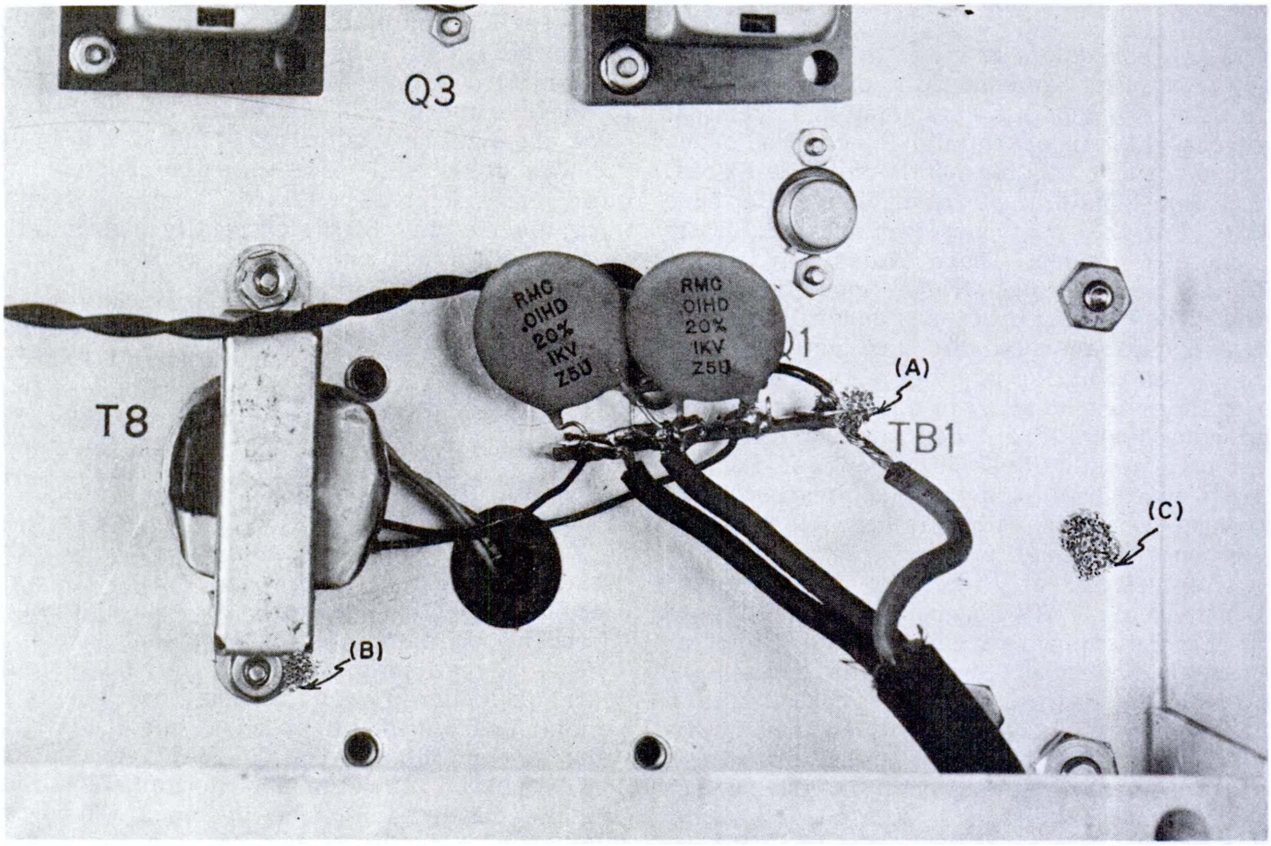
An ordinary flashlight cell serves as a good subject to explain electrochemical corrosion. (See fig. 18-26.) The outside container is made of zinc and serves as the anode which is corroded as the cell is operated. The cathode of the chemical cell is the carbon electrode in the center of the cell. The moist ammonium and zinc chloride paste within the zinc container is the electrolyte which electrically connects the carbon electrode with the zinc anode.

If a conductor is connected externally to the electrodes of a cell, electrons will flow under the influence of a difference of potential across the electrodes from the zinc (-) through the external circuit to the carbon (+) returning within the electrolyte to the zinc. As the electrons flow, the zinc coating will oxidize. This oxidation is the same as corrosion.

Since the only requirements for a cell are cathode, anode, and electrolyte, it should be apparent that the physical size of a cell is dependent only on the physical size of its components. A cell may be formed where a resistor lead is soldered to a terminal, two sheets of metal are joined, or around a rivet head and the adjacent metal. (See fig. 18-27 (A) and (B).) A cell may even be formed when an electrolyte is present on one piece of metal where two metallic crystals in the same alloy, but of



AT.274
Figure 18-26.—Dry cell, cross sectional view.



AT.275

Figure 18-27.—Electrochemical corrosion.

different composition, are in electrical contact with each other. (See fig. 18-27 (C).)

While the formation of one minute cell may be insignificant, it should be understood that a cell will continue to grow as long as the corrosion action is allowed to continue. This cell expansion may take place in a short period of time and become a significant structural safety factor due to the deterioration of the metal.

It should be apparent that the presence of an electrolyte allows corrosion to take place. The more efficient the electrolyte and the greater the potential difference between anode and cathode, the higher the corrosion rate (growth) will be. It should be noted that the anode and cathode are always present and cannot be removed; therefore, the solution to the problem of corrosion is to remove the electrolyte. When the electrolyte is removed, a cell no longer exists and corrosion is held to the minimum.

Both types of corrosion normally depend on moisture to form an electrolyte. Even moisture in the air is often sufficient to start the corrosion action. All attacks of corrosion start on the surface of the metal where it is exposed to the corrosive environment; and if allowed to progress, it will work its way into the core of the material. Since corrosion never originates in the core, there is always some form of evidence of corrosion on the surface.

PREVENTION OF CORROSION

Now that it is understood that the "villain" of corrosion is the electrolyte, the solution to corrosion prevention is to keep any electrolyte from coming into contact with the electrodes. This is accomplished by keeping a protective coating on the metallic surfaces.

Much has been done to improve the corrosion resistance of naval aircraft. This is in the area of improvement in materials, surface treatments, insulation, and protective finishes. All of these have been aimed at reducing maintenance effort as well as improving reliability. In spite of these improvements, corrosion and its control are very real problems that require a continuous preventive maintenance program.

Corrosion preventive maintenance includes the following special functions:

1. An adequate cleaning program.
2. Thorough periodic lubrication.
3. Detailed inspection for corrosion and failure of protective systems.
4. Prompt treatment of corrosion and touchup of damaged protective coating.

Inspection

Inspection for corrosion is a continuing problem and should be handled on a day-to-day basis. Overemphasizing a particular corrosion problem when it is discovered, and then forgetting about corrosion until the next crisis, is an unsafe, costly, and troublesome practice.

Most periodic maintenance requirement information has been placed on Maintenance Requirements Cards which are complete enough to cover all equipments in the aircraft. No equipment of the aircraft should go unchecked. Through experience, it will be learned that most equipments have trouble areas where corrosion will occur.

Protective Measures

An effective protection from corrosion requires the earliest possible repair of damaged protective coatings, including the removal of corrosion products and the restoration of corroded surfaces. This involves the maximum use of supplementary protective agents during any waiting periods or until such time as more positive protection can be restored. It must be a continuous program and recognized as a specific responsibility.

Periods of neglect or touchup maintenance, which may be necessary under operating conditions, should be followed by a period of concentrated effort to correct any deficiencies which have started. A successful preventive maintenance program will tend to reduce the effects of severe service environments and the susceptibility of most aircraft and equipment to damage by these environments.

ANTICORROSION MATERIALS.—During manufacture, electronic equipments are usually sprayed with a protective coating that seals out moisture, thus preventing corrosion and fungus growth. In repair of these equipments, it is sometimes necessary to remove the protective coating by scraping or by the use of a solvent cleaner.

After making circuit repairs, the protective coating should be replaced. Rosin fluxes form coatings on solder connections that prevent oxidation during and after the soldering process, thus providing one form of replacement. A good general rule is that materials used should be those covered and controlled by military specifications, preferably those authorized specifically for use on aircraft. Use nonspecification materials only in emergencies, or where specific instructions so direct.

FUNGUS-RESISTANT MATERIALS.—Fungus susceptibility of materials has long been a serious problem, particularly with electronic equipments which may be subjected to extremes of humidity under tropical temperatures. While the fungus itself is objectionable since it generally "fouls" all types of equipment, its most serious effect is the increased possibility of shorting and arcing because of its moisture content.

The fungus problem has been further aggravated in the past decade by the increased use of a large number of organic materials in equipment used in the Navy. These materials vary in nature and size from large sheets of reinforced plastic for structural components to special dielectric substances used in complex electronic gear.

Fungus removal generally follows the same procedures of corrosion removal.

CORROSION REMOVAL

In corrosion control, time is of the essence. Until the electrolyte is removed, the chemical reaction will continue. Although most of the electrolyte is removed, some will remain in inaccessible locations of the chassis or modules making the cleaning process particularly difficult.

When this occurs, the proper procedures and cleaning materials must be used. The remainder of this discussion will be devoted to the techniques and materials used in correcting this problem.

The extent of cleaning, using the following techniques, requires the decision of the Corrosion Control Officer assigned to the organization.

Drycleaning

When corrosion or salt crystals are discovered in a piece of equipment, as much of this as possible should be removed by dry methods. This entails breaking the solids from the metallic parts by wiping with a dry cloth or brushing with a stiff bristle brush. Care should be taken not to damage any of the components of the equipment.

Any loose residue should be removed by the use of low pressure dry air.

Although it may appear that all of the contamination has been removed, this generally is not the case. At this point a decision must be made as to the possibility of contamination existing in the inaccessible or undetectable areas of the equipment. If this decision indicates that contamination still remains in the equipment, then further steps must be taken in the form of liquid cleaning.

Fresh Water

Although immersion or flushing of electronic and other equipment in or with water violates previous training, fresh water is one of the agents used to remove salt water and deposits from equipments. After the equipment has been subjected to fresh water, the water must then be removed. This may be accomplished by dry air pressure, by the use of a spray (displacement) fluid, or by a drying oven.

DRY AIR PRESSURE.—If compressed air is not available, any type of compressor that will deliver clean dry air at 80 psi will be adequate to furnish air for spray cleaning and for blowing as much water as possible from the wet equipment before using the water-displacing fluid.

WATER-DISPLACING FLUID.—This fluid is generally available in pressurized aerosol cans or in drums and is called a spray-dry water-displacement composition. A paint spray gun or other spraying equipment for applying bulk water-displacing composition in a fine mist may be used if an aerosol-pressurized water-displacing composition is not available.

The equipment is sprayed with this composition, and then some means of drying such as heat oven, air pressure, or natural evaporation should be employed.

DRYING.—Forced draft ovens with accurate temperature control large enough to accommodate the equipment being cleaned are preferable for final drying of the cleaned equipment. If ovens are not available, a small room equipped with an exhaust fan and heaters can be used. The temperature in the drying facilities should be between 120° and 160°F, depending upon the temperature sensitivity of the equipment being dried. If a heated room is used for drying, its temperature should be at least 30°F above the ambient temperature.

Detergent

In some cases a detergent must be used. The detergent is available in aerosol type containers or in bulk form. Detergent is used because salt crystals have formed on the equipment or an oily deposit is present in the equipment. The detergent will dissolve the salt crystals and will also emulsify and suspend oil deposits in the solution. In either case, fresh water must be used to rinse the contaminated solution from the equipment.

Ultrasonic Tanks

An ultrasonic tank is a container for fresh water or a cleaning agent. The solution is vibrated either by a transducer or by forced air. The agitation helps remove particles from inaccessible areas of the electronic equipments. The frequency of the transducer is in the ultrasonic range (above 15 kilohertz) and accomplishes the cleaning in a much shorter period of time than the forced air. When equipment has been removed from an ultrasonic tank, the previously mentioned procedures for drying should be completed.

SALVAGE PROCEDURES

The following steps comprise the routine procedure for salvaging sea water contaminated electronic equipment:

1. Immediately after removal of the equipment from sea water contamination, the equipment should be flushed thoroughly with fresh water.
2. The equipment should be disassembled to units of a size that permits immersion in an ultrasonic bath and to allow better access of cleaning solutions.
3. Remove contamination with emulsion cleaning composition in the ultrasonic tank.
4. Rinse in an ultrasonic tank of fresh water or rinse with a fresh water spray.

5. Blow the rinse water from the equipment with clean compressed air and follow with an application of water displacing composition.
6. Dry in an oven or by natural evaporation.
7. Check for damage, repair and lubricate as required, then return to service.

Equipment which cannot be dismantled or is too large for cleaning in the ultrasonic tank can often be cleaned by spraying with a cleaning emulsion. Upon completion of the emulsion application, the equipment should be rinsed and dried as previously indicated.

MURPHY'S LAW

There is no doubt that all Aviation Fire Control Technicians are familiar with Ohm's law. There is another law with which the technician may not be quite so familiar. This law, known as Murphy's law, states that "IF AN AIRCRAFT PART CAN BE INSTALLED WRONG, NO MATTER HOW REMOTE THE POSSIBILITY, SOMEONE WILL INSTALL IT THAT WAY." To ignore this law can cause problems that range from embarrassment of the technician to actual destruction of an aircraft and possible loss of the pilot and/or crew. Each month The Naval Aviation Safety Review, Approach, presents the problems caused by maintenance personnel when Murphy's law was ignored.

For the AQ, the danger areas are installation of cable connector plugs on the wrong receptacles, crossing instrument lines, installing tubes in the wrong sockets, etc. The possibilities are endless, and the good maintenance technician must be constantly alert to the dangers. Do not become a victim of Murphy's law.

CHAPTER 19

RADAR MAINTENANCE

Radar maintenance, when compared to maintenance of other electronic equipment, is much more exacting and somewhat more complicated. It is possible, for instance, to determine to some degree the satisfactory operation of a radio receiver by listening to the tone and observing how much the gain control must be advanced to obtain sufficient volume. However, unlike most radio communication equipment, radar systems cannot be tested by observation alone to determine whether their performance is satisfactory.

In the field of radar, reliance on visual observation alone to judge the range capability and other data accuracy has been found to be so inaccurate as to be completely valueless. Careful and precise performance testing is the only procedure that will determine whether or not a radar set is operating at peak efficiency. Thus the AQ must become familiar with the techniques of checking a radar set to insure its proper performance.

Recent radar systems are provided with self-testing features called built-in tests (BIT). Typical tests will verify overall system target detection capability, angle tracking capability, and missile computation accuracy (for missile control). No test equipment is required for this type of testing since the BIT Box is used to "read out" the results of the specific tests. This type test also allows the operator to perform system test while airborne. The results of the in-flight test will often aid the technician in pinpointing any trouble that may have been encountered.

MAJOR UNIT CHECKS

Only the most frequent and difficult radar maintenance problems are discussed in this chapter since describing an entire radar testing procedure would be too lengthy. The checks, measurements, and adjustments receiving particular attention are those of the transmitter and receiver. These units seem to be the most difficult for the technician to maintain properly. The power supply, synchronizer, indicator, and antenna are also discussed, but not in great detail.

POWER SUPPLY

Power supplies that are commonly used in avionic equipment are either regulated or unregulated. An unregulated supply usually provides filtered but unregulated low B-plus (under 300 v d.c.) or high B-plus (over 300 v d.c.) in addition to a-c heater power for vacuum tubes and in some cases relay-operating power. The regulated power supplies consist of an unregulated supply and the associated circuitry necessary to regulate the B-plus output.

Basic Electronics contains a discussion of power supply operation and is not discussed here.

Power supplies used to provide the d-c voltage sources for operation of electronic equipments are of various types, such as half-wave and full-wave rectifiers. The type circuitry employed for a particular application depends on such factors as current and voltage load requirements, available space, weight, degree of voltage regulation required, etc. Electronic systems are generally complex and contain one or more power supplies which provide several voltage outputs. The design performance of these equipments depends upon the proper operation of the power supplies. For this reason, power supply tests are included in the preventive maintenance test procedures prepared for most equipments. Many equipments are provided with easily accessible test points for ease in performing these tests. The more common type of power supply test is a simple voltage reading taken with the equipment in operation.

To operate radar equipment, various d-c voltages are required. The transmitter requires a high voltage source capable of delivering a large current for short intervals of time. The regulation or ripple content of this voltage is not critical. The cathode ray tube requires a high accelerating voltage which is usually easy to regulate because the small load results in a low current drain. The plate voltage supply for the receiver and the indicator sweep circuits require a source of good regulation and very little ripple. Voltages are also required for relays, blower motors, antenna control motors, etc. Combinations of vacuum tubes, rectifiers, transformers, voltage dividers, etc., are used to provide these different voltages.

Power supplies of various types occur throughout the radar system because it is impractical to install all of them in a central location. Even though in some equipments the power supply may lose its identity as a separate unit, the function is still performed and must be tested and maintained at its rated performance.

Intermittent Troubles

Intermittent troubles are probably the most aggravating and irritating problem faced by the technician. The equipment always seems to be in proper operation while under observation, only to malfunction as soon as the technician turns his back. There is no single method for resolving this difficulty. The procedure to be used depends on the individual situation—the technician, the equipment, the available information, the peculiarities of the installation, etc. A thorough knowledge of the operation of the equipment, and an understanding of the most common causes of intermittent troubles should help in troubleshooting intermittent problems.

Some of the most common causes of intermittent troubles are loose vacuum tube elements, poor electrical connections, poor solder joints, leaky capacitors, arcing, broken terminal boards or printed circuit boards, fused conducting strips, and mechanical vibration. Vibration is usually associated with one or more of the others listed, either as a basic cause or as a contributing factor; therefore it should always be investigated early in the troubleshooting procedure. If the equipment seems to operate properly after a visual inspection fails to reveal the cause of the intermittent trouble, vibrate the equipment by tapping or jiggling while watching for indications of arcing, etc. If this fails to produce meaningful indications, methodical and patient troubleshooting procedures must be followed.

SYNCHRONIZER

Because the synchronizer is the unit which controls or synchronizes the entire radar set, the timing pulses and other signal voltages generated must be checked frequently, and then adjusted if necessary.

Note: Not all the radars on which an AQ will work will have a unit called a synchronizer, nor will there be a single unit which synchronizes the entire radar set. Several units may be used to provide synchronizing of the system as in the F-4J, AN/AWG-10 Radar System.

The pulse repetition frequency (PRF) will have several PRF selections, depending on the range or mode selected. In addition to establishing the PRF, the synchronizer usually produces the following signals—range sweep voltages, range marker signals, range strobe signals, and intensity gates. These signals and the circuits used to generate them were described in chapter 11.

Extensive use of the oscilloscope is required in making checks and alinements of the synchronizer, since the signals and voltages previously mentioned require precise time measurement and, in some cases, measurement of signal amplitude. Operation of the oscilloscope is not difficult; the problem is the proper interpretation of the observed waveforms. This is described in detail in chapter 17. Although the synchronizer checks must be made with great care and precision, they are relatively simple when the proper procedures are followed.

In the event that adjustment or alinement is required, the currently approved alinement procedures, as described in the appropriate Maintenance Instructions Manual, must be rigidly followed. Synchronizer alinement is normally accomplished using a step-by-step procedure, the steps being performed in a specific sequence. Each step in its turn depends on the one previous to it. Reliance on memory for alinement is not a good practice, unless the adjustments are relatively few and simple.

INDICATOR

The pilot and the navigator depend on the information displayed on the indicator to fly the aircraft into the proper position for dropping a bomb or releasing a missile. If what they observe on the face of the indicator is not properly positioned or if information is missing, mission effectiveness is reduced or the mission could fail completely. In some cases the aircraft and the lives of the crew could be placed in grave danger.

Today's airborne weapons systems radars utilize many different types of indicators. A typical indicator is illustrated in figure 19-1. Some or all of the following information may be displayed on an indicator of this type:

1. Target range and bearing.
2. Artificial horizon.
3. Antenna position.
4. Steering information (target relative position).
5. Range rate and range to go.
6. Warning signal lights and various reference lines scribed into the face of the indicator.

That portion of the above information which is written on the face of the indicator by the electron gun(s) must be positioned properly in order to be of value to the operator. The adjustments required during an alinement check are relatively easy to perform, but must be exactly as prescribed in the alinement procedure.

Many of the positioning voltage adjustments are similar to those of the oscilloscope display voltages. The main difference is that each of the displayed items, such as artifical horizon, range circle, etc., have separate vertical and horizontal centering adjustments. One adjustment worthy of special attention is steering information deflection sensitivity. Steering information is derived from the antenna's position. Therefore, for a given amount of antenna displacement from center, the steering information must be deflected by a proper amount in order for the pilot to successfully track the target. If sensitivity is too great, the pilot will have trouble making a smooth tracking run. If the sensitivity is too low, steering information is sluggish, and will lag far behind the actual position of the antenna.

Intensity should be set so the trace is just below the threshold of visibility as it sweeps back and forth. Then, any target return is easily discernible. With the intensity properly adjusted, the various strobes (range markers, cursors, artificial-horizon bars, etc.) should be set at a comfortable viewing level.

NOTE: Some indicators are equipped with viewing hoods. In such a case, intensity is adjusted with the hood in place with no external light striking the face of the indicator.

Focus adjustments should be made so the presentations are sharply defined. If the presentation does not remain sharp at all positions on the face of the indicator, the astigmatism control must be adjusted, along with the focus control, until the presentation is sharp

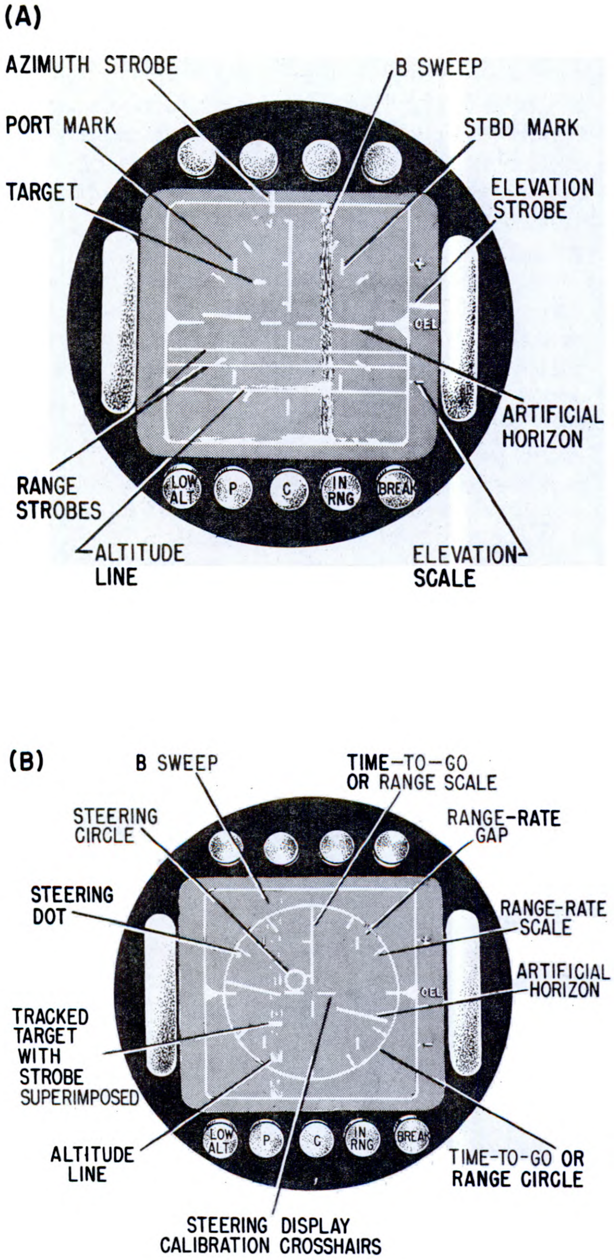


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Figure 19-1.—Typical indicator display. (A) Search; (B) track.

and clear regardless of its position on the face of the indicator.

Where the indication is positioned in azimuth or elevation by the position of the control handle or antenna, make sure the indication moves an equal amount on both sides of center and that it is centered when the antenna is centered.

Check all indicator lamps that are used for illumination of control panels, range indications, and warnings. Replace any that are burned out.

Two more items that discourage an operator are range circles that are not round and target position on the B trace (in the case of a B type scan presentation). If circles are not properly rounded, the range indication is distorted and may confuse the operator. The other item is the adjustment of the B trace sweep length as presented on the indicator. If the B trace is not of the correct length, the target appears at a range which is in error, as far as the operator can judge. For instance, if a radar has a 50-mile range, the B trace length is 50 miles and should sweep from the bottom of the scope to the top. If operating on the 50-mile scale, a target at an actual range of 25 miles should appear halfway up the sweep (at the center of the scope). With an improperly adjusted B trace, the target will appear at a range other than 25 miles and possible cause confusion for the operator.

Remember, in order to receive maximum advantage from the use of a radar system, the indicator must present all information in the best possible form. If this is not done, the operator loses confidence in the equipment and failure of the mission may result.

ANTENNA

The antenna operates as part of a servosystem. Therefore, most antenna functions are checked along with other portions of the radar system. Alinement of a typical antenna servosystem is described in chapter 6.

TRANSMITTER

The measurement of frequencies employed in radar operation falls into two general categories—transmitter frequency and receiver frequency.

For the transmitter operation of any given radar system, a range of frequencies is assigned for that system. Therefore, the transmitter must operate within this band of assigned frequencies if normal operation is to be expected. Transmitter operation is restricted to a certain range of frequencies for the following reasons:

1. The associated waveguide tuning adjustments cover only a limited range of frequencies.
2. Interference between radars used for different types of services could result if all radars were permitted to operate in the same band. For this reason, airborne S-band and shipboard S-band radars usually operate in different parts of the band.

Radar transmitters may be either fixed in frequency or tunable. Tunable transmitters may be adjusted to any frequency within the operating band; this is a very desirable feature where several radars are in use in a limited area, because each one may be tuned to a different frequency to prevent interference. In addition, when jamming is present, a different frequency may be free of the jamming signal. Since the operating bands are fairly wide, however, transmitter frequency tests do not require extreme accuracy.

Frequency Measurements

The transmitted frequency of a microwave-radar set is readily measured by using a resonant cavity wavemeter as described in chapter 17 of this manual. The resonant cavity functions as an absorption type wavemeter. When tuned to the frequency of the transmitter, the cavity absorbs some of the microwave power. This reduction of power is indicated as a dip on the power monitor (meter) or synchroscope.

A convenient method of coupling the radar transmitter to the frequency meter is by use of a coaxial cable. One end of this cable is connected to the radar directional coupler, while the other is connected to the frequency meter input.

Figure 19-2 shows a block diagram set up to measure power or frequency. When tuning the frequency meter, the control should be moved slowly. Otherwise it is possible to pass the resonance frequency without knowing it. The reason for this is that the power is detected by a thermistor which takes a short time to heat and react to the power applied to it.

The resonant frequency of the radar may also be indicated on the synchroscope. The reduction in power caused by absorption in the

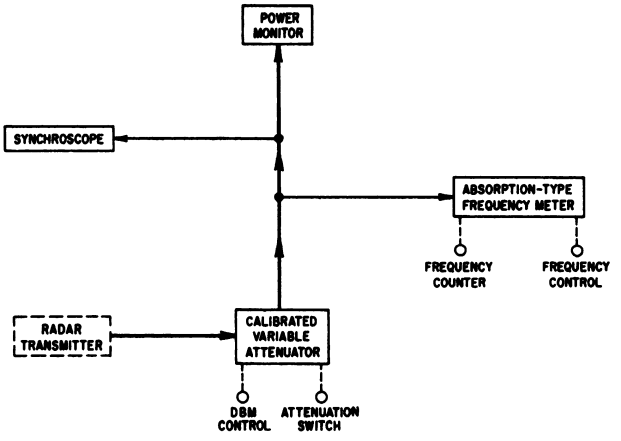

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Figure 19-2.—Power and frequency measurements, block diagram.

resonant cavity is apparent by a decrease in pulse amplitude on the CRT. This dip is usually easier to detect than the power meter dip, as the scope responds more quickly than the power meter. Final tuning, however, should always be done by the meter indication. Transmitter frequency may also be measured during spectrum observation.

Spectrum observation is the display of the magnetron's output on a synchroscope. By this method the technician may readily determine visually whether or not the magnetron is operating properly. Figure 19-3 shows an ideal spectrum of a pulsed magnetron. Note that the side lobes are very low compared to the main lobe, and that the main lobe falls off to zero on either side of the carrier frequency.

Figure 19-4 shows several examples of transmitter spectral displays that are less than ideal. In general, the distortion resulting from frequency modulation (fig. 19-4 (A) and (B)) is far more undesirable than distortion resulting from amplitude modulation (fig. 19-4 (C)). Both frequency and amplitude modulation may be present in a spectral display (fig. 19-4 (D)).

Poor spectra may be caused by a defective magnetron, mismatch in the RF section (pulling), improper pulse shape or amplitude from the modulator (pushing), or reflections from nearby objects (pulling). Firing the transmitter into a dummy load will usually isolate the trouble if it is caused by external influences such as waveguides, rotating joints, or other reflections.

Figure 19-5 illustrates a spectral display as it would appear on the synchroscope. Note the small break in the base at the center of the display. This is a frequency marker that is positioned by the frequency control on the test

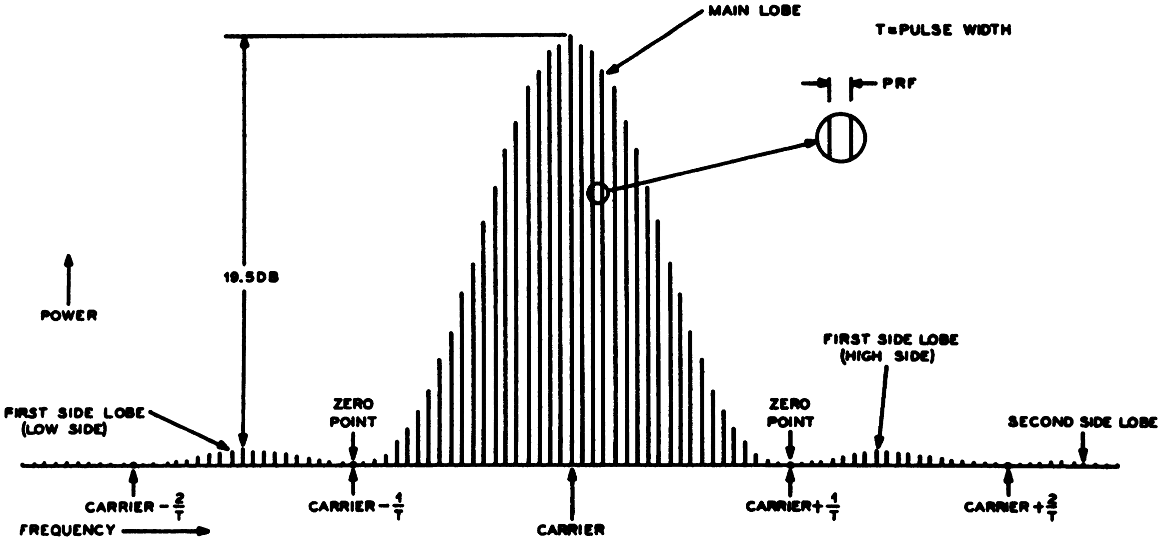

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Figure 19-3.—Ideal spectrum of a pulsed magnetron.

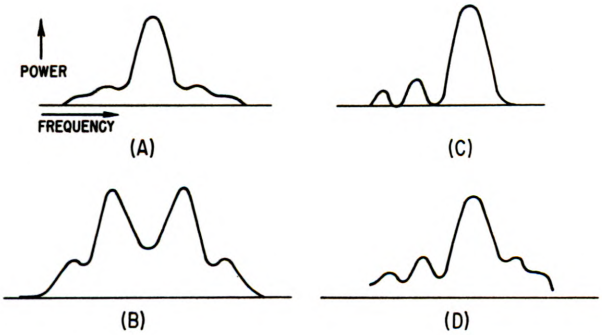

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Figure 19-4.—Magnetron spectral displays showing distortion.

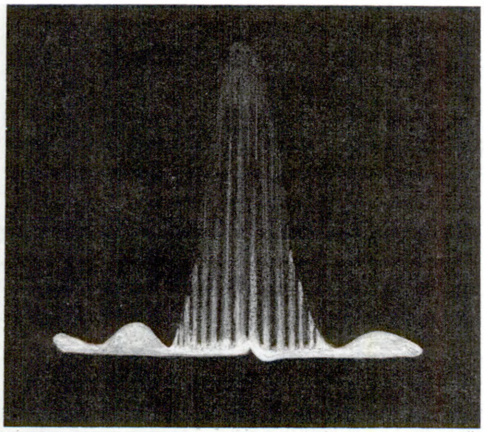

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Figure 19-5.—Spectral display showing frequency meter dip.

set. This pip occurs at the test set oscillator frequency, not at the radar-transmitter frequency. Therefore the frequency reading must be corrected by adding or subtracting the IF frequency (usually 45 megahertz). Another method would be to measure the frequency of the display with the test set oscillator adjusted above the radar frequency. Then measure the display with the test set oscillator below the radar frequency. Adding the two indicated frequencies together and dividing by 2 will give the true transmitter frequency even though the IF frequency is unknown.

Power Measurements

High peak power in a radar transmitter is desirable to produce a strong echo at long ranges. Low average power is desirable, as it enables the transmitter components to be made smaller and more compact with less regard for cooling. It thus becomes apparent that a low duty cycle is desirable. The relationships of peak power, average power, and duty cycle were described in chapter 10. The peak power which a set is capable of developing is primarily a design consideration. It is dependent upon the interrelationship between peak and average power and between pulse width and pulse repetition time, or duty cycle. A means of insuring optimum power performance is built into most radar sets by means of a control that adjusts magnetron current. This is especially desirable in radars incorporating tunable magnetrons. The operator is thus able to adjust magnetron current to recommended optimum values.

In making power measurements on a radar transmitter, there are two methods of sampling the power output of the transmitter. One method uses a pickup horn in front of the radar antenna. When this method is used, the placement of the pickup horn in relation to the antenna is extremely critical as air losses must be taken into consideration. A more satisfactory method is to connect the test set to the radar directional coupler. This avoids the difficulty of measuring or calculating air losses.

When the power (in dbm) is read from the attenuator dial, the losses must be added to this figure. This is easily done by adding the attenuation (in db) of the directional coupler and the loss (in db) of the coaxial cable to the attenuator dial reading. The cable losses are usually indicated on a tag attached to the cable and usual values are about 1 db per foot of coaxial cable. The loss (in db) of the directional coupler is found on a tag or nameplate attached to the directional coupler and is usually 20 db or more.

Testing a radar set for average power output might proceed on the following plan: When the test set and radar are warmed up and operating, the appropriate connections are made in accordance with the operation instructions for the test set.

NOTE: Two precautions should be observed when connections are made to the test set. They are as follows:

1. Be sure the attenuation controls are set for maximum attenuation to avoid damaging the test set with power levels that are too high.

2. Turn the frequency meter off resonance so that none of the power will be lost in the resonant cavity.

The attenuation controls are then adjusted to decrease attenuation until the power meter reads 1 milliwatt. The attenuation (in dbm) may then be read from the attenuator dial. To this is added the attenuation of the directional coupler and the coaxial cable. The total attenuation is then indicative of the transmitter power.

Figure 19-6 shows a graph that can be used to convert power in dbm to average power in watts. This can also be accomplished mathematically by the equation

$$\text{dbm} = 10 \log \frac{P2}{P1}$$

where dbm is the total attenuation, P2 is the unknown output power in milliwatts, and P1 is the 1-milliwatt reference level.

For example, suppose the power measurement of a radar set shows a dial reading of 21 dbm on the test set, the directional coupler has 20 db, and the coaxial cable has 1 db per foot and is 8 feet long. Inserting these values in the equation gives

$$49 \text{ dbm} = 10 \log \frac{P2}{P1}$$

Rearranging and substituting 1 mw (reference power) for P1 gives

$$4.9 = \log \frac{P2}{1 \text{ mw}}$$

$$10^{4.9} = \frac{P2}{1 \text{ mw}}; \; P2 = 10^{4.9} \text{ x } 1 \text{ mw}$$

$$P2 = 10^{0.9} \text{ x } 10^{4} \text{ x } 1 \text{ mw}$$

$$P2 = 7.94 \text{ x } 10^{4} \text{ mw} = 79400 \text{ mw}$$

$$P2 = 79.4 \text{ watts.}$$

This corresponds closely to the value of 80 watts that is arrived at when the graph (fig. 19-6) is used.

To find the peak power of the radar, the chart shown in figure 19-7 may be used. The PRF and pulse width must be known. They may be obtained by measurement or from descriptive data on the radar.

Assuming a pulse width of 0.8 microseconds and a PRF of 1,706 pulses per second, lay a straightedge on the chart, connecting point A (pulse length) and point B (PRF). At point C read the value of db (28.6). This value is added to the dbm reading obtained in the average power measurement and the peak power can then be calculated. To find the peak power in the case previously cited, add 28.6 db to 49 dbm for a total of 77.6 dbm. We cannot use the graph of figure 19-6 in this case as it does not go high enough. However, using the mathematical equation above, the result is

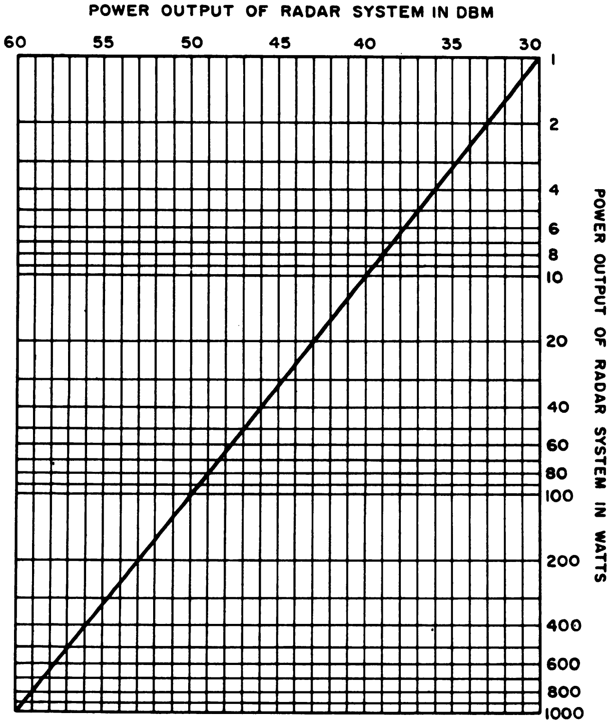

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Figure 19-6.—Conversion of power in dbm to power in watts.

$$77.6 \text{ dbm} = 10 \log \frac{P2}{P1}$$

$$10^{7.76} = \frac{P2}{1 \text{ mw}}$$

$$10^{7.76} = P2$$

$$5.75 \text{ x } 10 \quad \text{mw} = P2$$

$$P2 = 57.5 \text{ kw}$$

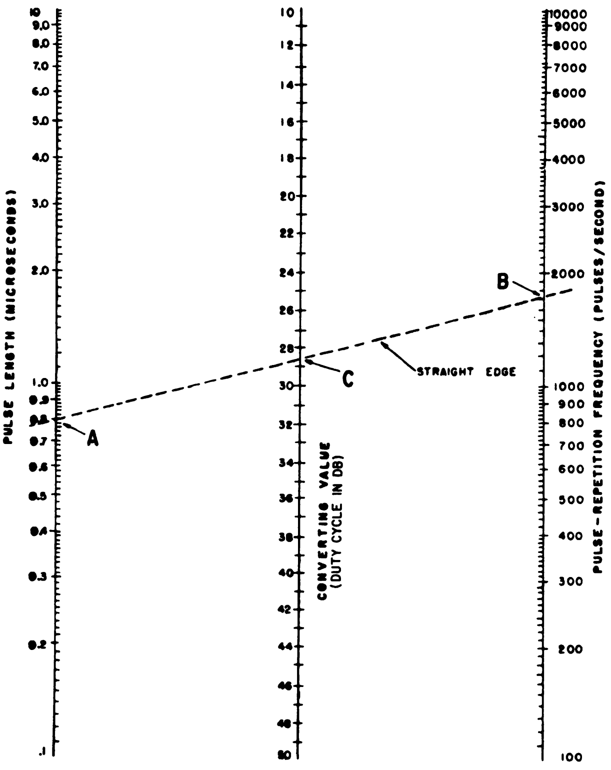

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Figure 19-7.—Average to peak (duty cycle) power conversion chart.

Two things become apparent: Peak power is much greater than average power, and a 28.6-db gain represents a tremendous increase in power.

RECEIVER

The performance of a radar receiver is determined by several factors, most of which are evolved and established in the design engineering of the equipment. In the paragraphs to follow, only those factors which are concerned with maintenance are considered. The most important of these factors are receiver sensitivity, which includes noise figure determination and minimum discernible signal (MDS) measurement; TR recovery time; receiver recovery time; and receiver bandwidth.

Many radar systems have circuits which are included to serve a special function. Three of these special circuits commonly encountered in aviation weapons systems radar are instantaneous automatic gain control (IAGC), sensitivity time control (STC), and fast time constant (FTC). These circuits may be found in combination or alone depending upon the purpose of the radar. In the test methods and procedures about to be described, the special functions should be disabled. If an automatic frequency control (AFC) circuit is included in the radar, it may be permitted to operate during the receiver tests. A good check on AFC is to make the tests specified for manual tuning, then switch to AFC. If the AFC circuit is normal, the signal indications will not change.

Inefficient range performance of a radar system can be caused by troubles in the radar receiver. This fact is brought about mainly by the great number of adjustments and components associated with the receiver. Loss of receiver sensitivity has the same effect on range as a decrease of transmitter power. For example, a 6-db loss of receiver sensitivity shortens the effective range of a radar just as much as a 6-db loss in transmitter power. Such a drop in transmitter power is very evident and, therefore, is easy to detect. On the other hand, a loss in receiver sensitivity, which can easily result from a slight misadjustment in the receiver, is very difficult to detect unless accurate measurements are made.

Figure 19-8 shows a comparison of radar system performance versus maximum range. The loss of system performance in db includes both transmitter and receiver losses. It should be noted that with a loss of 5 db in both receiver and transmitter (total of 10 percent) performance, only 55 percent of the system's maximum range is realized.

The sensitivity of the receiver determines the ability of the radar to pick up weak signals. Greater sensitivity then indicates that the receiver can pick up weaker signals. Sensitivity is measured by determining the power level of the MDS. MDS is defined as the weakest signal that produces a visible receiver output, and its value is determined by the receiver output noise level, which tends to obscure weak signals. It follows, therefore, that an MDS measurement is dependent upon the receiver noise level, and that measuring either one of these quantities will give an indication of receiver sensitivity.

Many weapons control systems have built-in receiver sensitivity test circuits, such as BIT target generators or ringing oscillators that

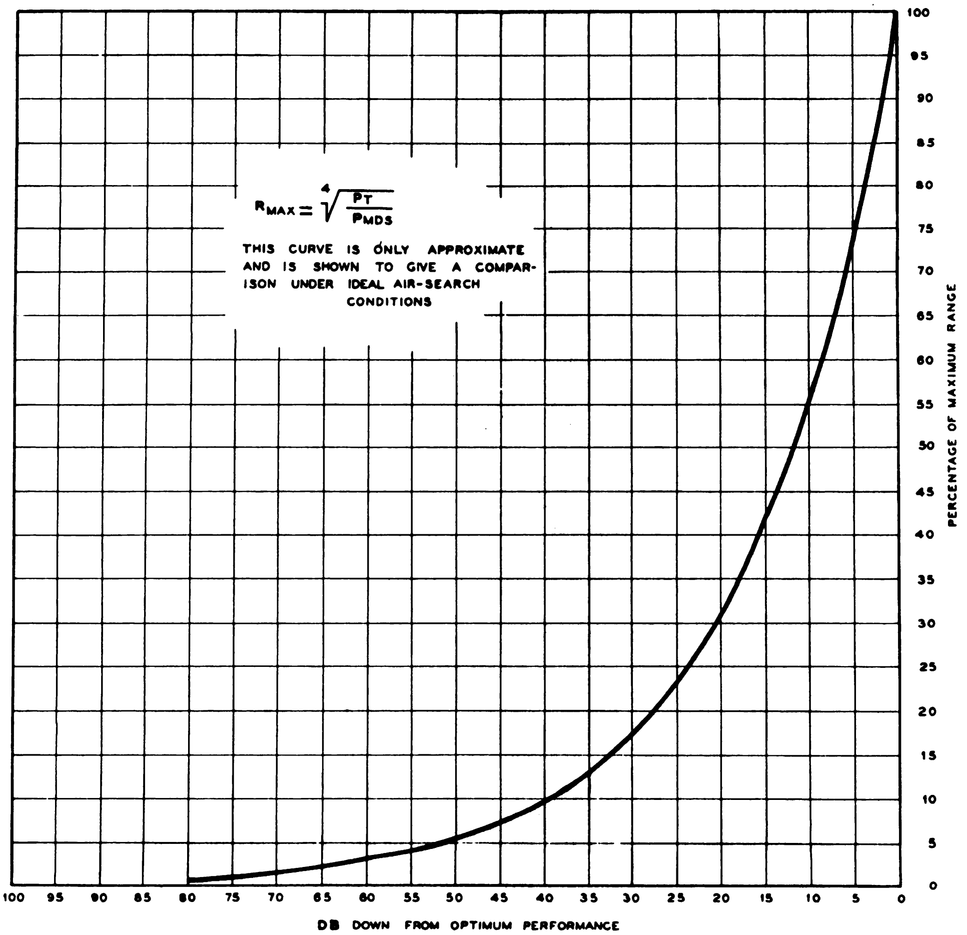

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Figure 19-8.—System performance versus maximum range.

give an indication to the technician or operator the sensitivity of the receiver. (See Basic Electronics for a discussion on noise in amplifier circuits.)

The measurement of a minimum discernible signal consists of measuring the power of a pulse whose level is just sufficient to produce a visible receiver output. If a radar receiver has the specified MDS level, the noise figure should be correct also. Therefore, measurement of the MDS is a satisfactory substitute for a noise-figure determination, and is less complicated. Correct pulse length must be used; and when readings are taken periodically for comparison purposes, the identical pulse length must be used each time. Maintenance instructions for the radar set will usually specify the pulse length to be used in receiver sensitivity tests. In most cases it will be the same as the transmitter pulse.

Receiver Frequency Measurement

Before any measurements of receiver sensitivity can be made, the receiver must be accurately tuned to the radar-transmitter frequency. To measure the receiver frequency, the test set is connected to the radar set directional coupler. (Receiver frequency may be measured with the test antenna; however, to get accurate results, the sensitivity tests that usually follow frequency tests must be made using the directional coupler.)

The test set is tuned to the radar-transmitter frequency as described in the Maintenance Instruction Manual for the test set. Then the test set dbm control is used to increase attenuation until grass appears on the test set CRT. The oscillator frequency control is then adjusted until the grass disappears from the CRT. These adjustments are repeated alternately until a very small change in the oscillator frequency or any increase in attenuation causes grass to appear. The frequency control is then adjusted to cause a maximum dip on the power meter. The reading on the frequency counter now indicates receiver frequency. If this reading differs from the previously measured transmitter frequency, the radar-receiver local oscillator is improperly adjusted, or the transmitter frequency may have drifted.

Local Oscillator Adjustments

To adjust the local oscillator, the test set is tuned according to the Maintenance Instructions Manual and the transmitter frequency is then measured. This adjusts the test set to the transmitter frequency. The frequency control is then adjusted at least one turn away from the transmitter frequency, and the radar local oscillator is adjusted for a reduction of grass on the test set CRT. At this point, the radar crystal current should be adjusted, if necessary, to the level specified in the Maintenance Instructions Manual for the radar set.

Increase the attenuation with the dbm control until grass appears. Repeat the local oscillator and attenuation adjustments until any change in the local-oscillator frequency or increase of the attenuation causes grass to appear on the CRT. The receiver is then tuned to the transmitter frequency. The receiver is now ready for sensitivity tests.

Local Oscillator Replacement

When a klystron local oscillator fails to produce an output of correct frequency or amplitude, it must be replaced. Replacement of plug-in type klystrons is a relatively simple matter. However, caution should be exercised to insure that the tube or its probe is not damaged. Voltage checks should be made at the filament, cathode, and reflector connections as improper voltages may cause the klystron to be destroyed.

Flange-mounted klystrons require more work in replacement than the plug-in type. They may be mounted directly to a section of the mixer waveguide, or they may be electrically insulated from the waveguide. If such is the case, insure that all insulating washers, gaskets, and spacers are replaced in such a manner as to maintain the electrical isolation of the klystron from the waveguide. A final check with an ohmmeter before the power is turned on will establish whether or not the insulation is intact. The klystron is then tuned to the correct frequency as previously described.

CAUTION: When the klystron is insulated from the waveguide section, there is normally a negative 250-volt potential applied to the shell. Care must be exercised to prevent physical contact with the klystron while power is applied to the set.

Receiver Sensitivity Tests

There are two basic methods of measuring receiver sensitivity. One method is the pulse method where a pulse of measured amplitude and width is generated and coupled to the radar receiver. This method is rather difficult as consistent results require that the signal generator be tuned very accurately to the receiver frequency.

The second method employs an FM generator to sweep the signal generator across the receiver frequency. This method insures that the test signal is within the pass band of the receiver.

PULSE METHOD.—With the pulse method, the test set is connected for signal generator operation and set to the receiver frequency. Then the test set signal is adjusted to the 1-mw reference level with the uncalibrated variable attenuator. The DELAY AND SWEEP LENGTH control is used to position and identify the test set pulse on the CRT. The pulse should be positioned away from other targets and ground clutter. (See fig. 19-9 (A).)

Radar-receiver gain should be adjusted so the noise signal (grass) on the CRT is about one-half that of the radar-transmitter pulse. The signal gain control on the test set should be adjusted until the grass is about 1/2 inch high. Adjust the PULSE OR GATE WIDTH control to the width of the transmitter pulse. Increasing the attenuation with the dbm control causes the signal to decrease in amplitude.

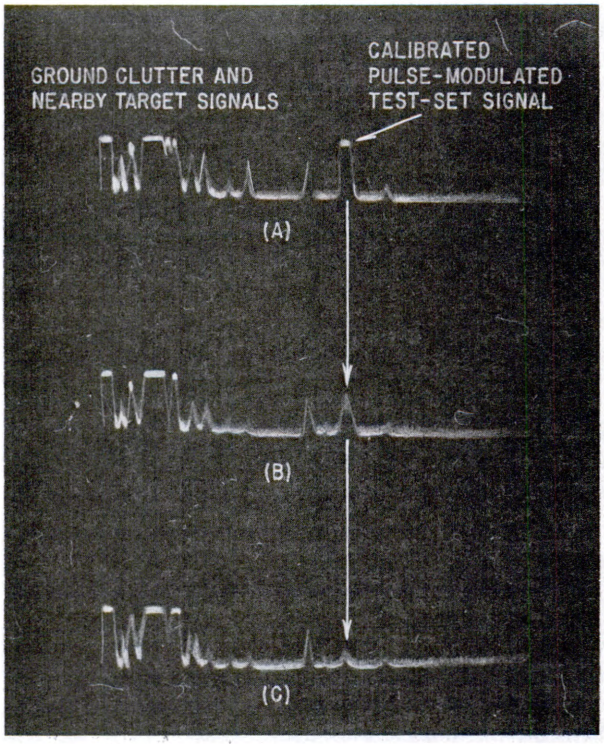

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Figure 19-9.—Measuring receiver sensitivity with pulse generator. (A) Large signal; (B) small signal; (C) signal just disappearing into noise.

(See fig. 19-9 (B).) The attenuation should be increased until the signal is no longer discernible in the grass. (See fig. 19-9 (C).) Rocking the delay multiplier control will cause the test set signal to move back and forth, making the test set signal easier to identify in the grass.

The sensitivity of the receiver is equal to the sum of the reading on the DBM control, the attenuation of the directional coupler, and the attenuation of the RF cable. Receiver sensitivity is expressed as a negative db; that is, -90 db expresses the sensitivity of a receiver that can detect a signal 90 db down from the 1-mw reference level.

FM METHOD.—The FM method of measuring receiver sensitivity offers two main advantages over the pulse method; tuning of the test set to the receiver frequency is not as critical, and receiver bandwidth tests can be made with relatively few changes in test set adjustments after sensitivity tests have been made. The procedure for measuring MDS is given in the steps listed below:

1. Set the SIGNAL-WIDTH control to maximum (CW).
2. Adjust the REFLECTOR control for maximum klystron output as indicated on the power meter.
3. Tune the klystron to approximate radar frequency by adjusting the frequency meter to the frequency of the radar transmitter and tuning the OSC FREQUENCY control for a dip in the power meter reading.

Since the klystron mode is fairly broad, extreme accuracy in tuning the klystron is not necessary. For example, the width of the flat portion of an X-band klystron is about 10 megahertz; therefore, the tuning accuracy required is ±5 megahertz.

4. If necessary, adjust the REFLECTOR control again for maximum output. If a sizable adjustment is required, repeat step 3.
5. Adjust the uncalibrated attenuator for a 1-mw indication.
6. Set the receiver gain control for about 1/2 inch of grass on the CRT indicator.
7. Reduce the SIGNAL WIDTH control setting until the pulse is seen on the CRT. (See fig. 19-10 (A).) Decrease the attenuation of the dbm control as necessary to obtain a pulse on the CRT.
8. If necessary, adjust the REFLECTOR control to position the echo pulse in a target free area. If more than one mode of the klystron is visible (fig. 19-10 (B)), use the largest one.
9. Adjust the SIGNAL WIDTH control for the desired pulse width. This will normally be the same as the transmitter pulse.
10. Set the DBM control for minimum discernible signal as described for the pulse method of testing receiver sensitivity, rocking the REFLECTOR control to help distinguish the signal.
11. Find the total attenuation in db. The value obtained is the MDS in db below 1 mw (-dbm). Total attenuation equals coupling loss plus cable loss plus attenuator reading (all in db).

Receiver Bandwidth Tests

Receiver bandwidth is defined as the frequency spread between the half-power points on the receiver response curve. Receiver

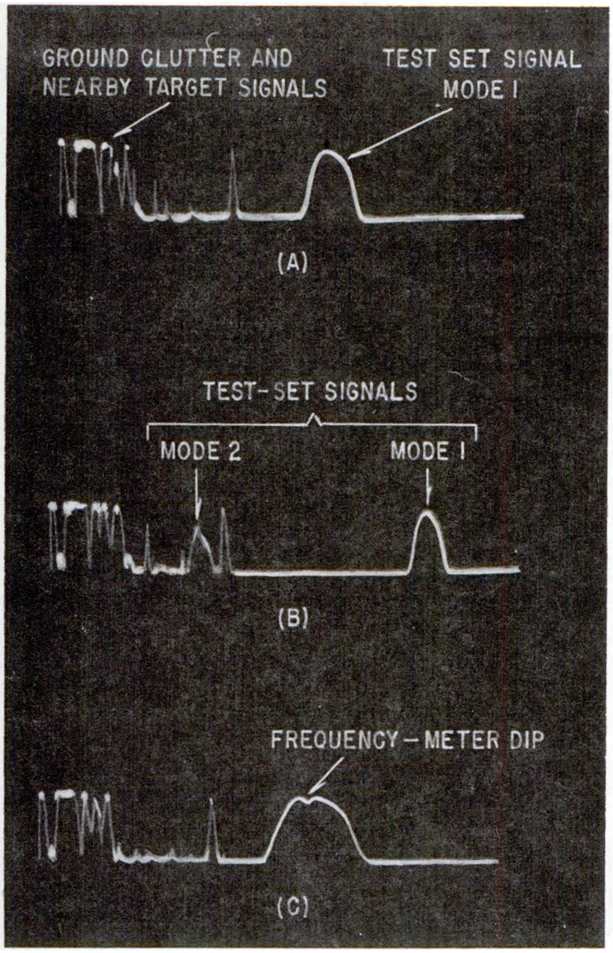

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Figure 19-10.—Measuring receiver sensitivity with an FM generator. (A) Bandpass curve, signal width control near center of range; (B) signal width control near MIN; (C) signal width control near CW, frequency meter dip near center.

bandwidth is specified for each radar, but wide variations are tolerated. If either the bandwidth or the shape of the receiver response curve is not within tolerances, a detailed check of circuit components may be necessary. Remember that a considerable change in the value of circuit components is required to alter the response materially. It is suggested that the receiver response be checked after any extensive repair to an IF amplifier.

Figure 19-11 shows a typical response curve of a radar receiver. The half-power points are shown as 3 db below maximum (midfrequency) response. Since the curve is plotted in terms of voltage, these points are also represented by the 70.7 percent voltage points ($\sqrt{1/2} = .707$) as shown in the figure.

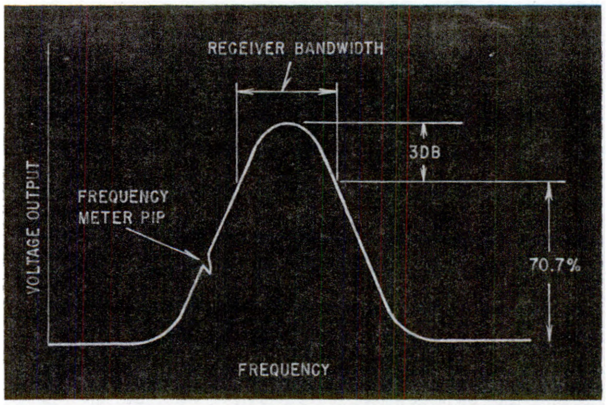

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Figure 19-11.—Receiver response curve.

The bandwidth test procedure, used when the receiver is operating as an integral part of the radar system, is easily made after checking the MDS and is given below:

1. With the equipment connected in the same manner as for the FM method of receiver sensitivity measurements, turn the SIGNAL WIDTH control to the width of the transmitter pulse. (See fig. 19-12.)
2. Adjust receiver gain so that the noise (grass) amplitude is just barely visible.
3. Adjust the calibrated attenuator to produce a pulse amplitude below receiver saturation level (no flattening of the top of the signal).
4. Tune the frequency meter until the response curve shows an absorption pip at one of the half-power points. Read the frequency, then repeat for the other half-power point. (See fig. 19-12 (B) and (C).) The difference between these two frequencies is the receiver bandwidth.

The half-power points may be located very easily by the following method:

1. Note the attenuator dial reading, following step 3 above.
2. Increase the attenuator reading 3 db and set the top of the signal even with one of the horizontal reference lines on the grid of the CRT overlay.

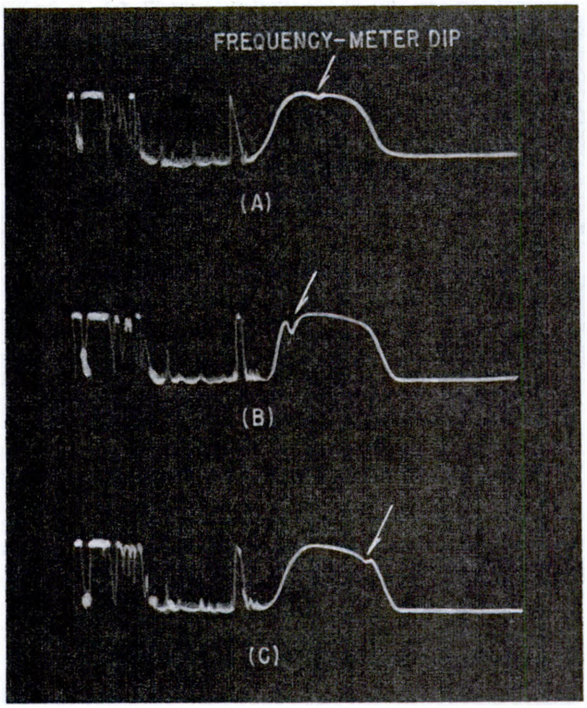

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Figure 19-12.—Typical bandwidth measurement pattern. (A) Frequency meter dip centered on top of bandpass curve; (B) frequency meter dip at left half-power point; (C) frequency meter dip at right half-power point.

3. Return the attenuator to the previous setting.

4. The half-power points are at the points where the signal crosses the horizontal reference line used in step 2.

TR Recovery Time

The time required to permit TR recovery is determined by the time it takes the TR switch to de-ionize after each transmitter pulse. It is usually defined as the time required for the receiver to return to within 6 db of normal sensitivity after the end of the transmitter pulse. However, some manufacturers use the time required for the sensitivity to return to within 3 db of normal or to full sensitivity. TR recovery time is the factor that limits the minimum range of a radar because the radar receiver is unable to receive signals until the TR switch is de-ionized. In various radar sets, the recovery time may vary from about 3 to 20 microseconds.

The primary function of the TR section is to protect the crystal detector from the powerful transmitter pulse. Even the best TR switches allow some power to leak through; but when the switch is functioning properly, the leakage power is so small that it does not damage the crystal. It has been found, however, that the useful life of a TR tube is limited because the amount of leakage and the recovery time increase with use.

To insure efficient performance, some technicians make it a policy to replace the tube after a given number of hours of use. A better practice is to measure the TR recovery time at frequent intervals and make a graph or chart, which will immediately disclose any change in performance. Figure 19-13 shows how the recovery time is correlated with leakage power. Note that the end of the useful life of the TR tube is indicated by an increase in recovery time.

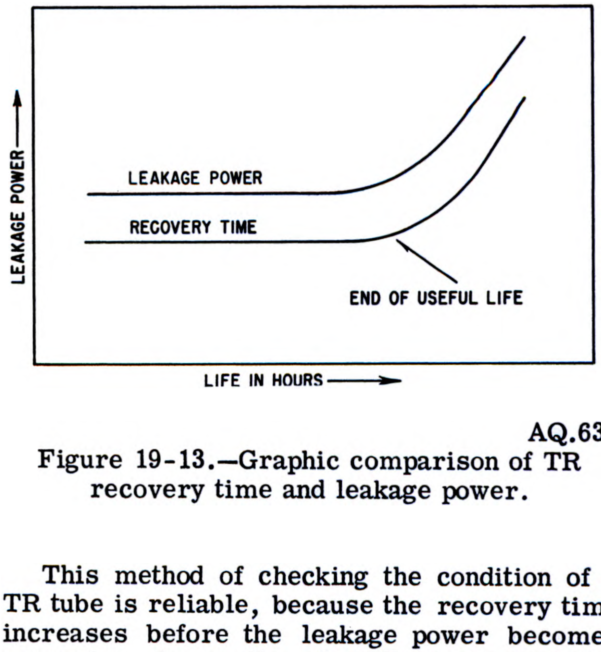

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Figure 19-13.—Graphic comparison of TR recovery time and leakage power.

This method of checking the condition of a TR tube is reliable, because the recovery time increases before the leakage power becomes excessive. In practice, the TR tube is replaced when any sharp increase in recovery time becomes apparent. Ambient temperature has an effect on recovery time. The colder a TR tube, the greater is its recovery time. When tests are conducted under widely varying temperature conditions, this effect must be considered.

One method used in testing a TR tube is to measure the keep-alive current. This current maintains the TR tube partially ionized to make the firing more reliable, and thus helps protect the crystal. The current is usually about 100 microamperes, and falls off as the end of the TR tube life approaches. Another method is to measure the keep-alive voltage between the plate and ground of the TR tube when the voltage source is known to have the correct output, and to record this voltage for use as reference for future checks. However, these checks are not as reliable as a recovery time test.

TR recovery time can be tested by means of a setup that utilizes a signal generator of either the FM or the pulsed type. Using either an FM or pulsed signal generator, the TR revovery time test is conducted by performing the following steps:

1. The same test setup used for the measurement of MDS is utilized for this test.
2. Set the receiver gain to indicate noise signals of about 1/8-inch amplitude on the CRT.
3. Adjust the calibrated attenuator to give a pulse amplitude about halfway between the noise level and saturation. Note the attenuator reading.
4. Reduce the attenuator setting by 6 db.
5. Rotate the REFLECTOR control to position the pulse closer to the transmitter pulse. Continue rotation of the REFLECTOR control until the pulse amplitude drops to the level established in step 3.
6. Read the range at which the pulse is now located. The value is the 6-db recovery time or the recovery time to within 6 db for normal receiver sensitivity. Recovery time may be indicated in either microseconds, miles, or yards, as long as subsequent readings are in the same units.

The AQ should realize that the above method is only one of several methods for measuring TR recovery time.

Crystal Matching

Many pulsed microwave equipments require matched sets of detector crystals for satisfactory operation. The matching of crystals may be accomplished under operating conditions, without elaborate calibration procedures, using normally available test equipment. In this discussion "matching" indicates that if the same amount of pulsed RF energy is applied to two or more detector crystals, the output pulses will not vary by more than a given ratio. If a given signal produces a 0.004-volt peak-to-peak pulse from one crystal and a 0.005-volt peak-to-peak pulse from a second crystal, the ratio is 5 to 4, or 1.2. Converting this to decibels,

$$20 \log 1.2 = 20\ (0.08) = 1.6 \text{ db}$$

Thus these crystals match within 1.6 db.

A practical method which is usable is indicated in figure 19-14. It is used to measure the calibrated power (supplied by the pulsed signal generator) required to produce a prescribed output (indicated on the oscilloscope). If two crystals require -15.5 dbm and -16 dbm, respectively, to produce a 0.004-volt peak-to-peak pulse, these crystals match within 0.5 db.

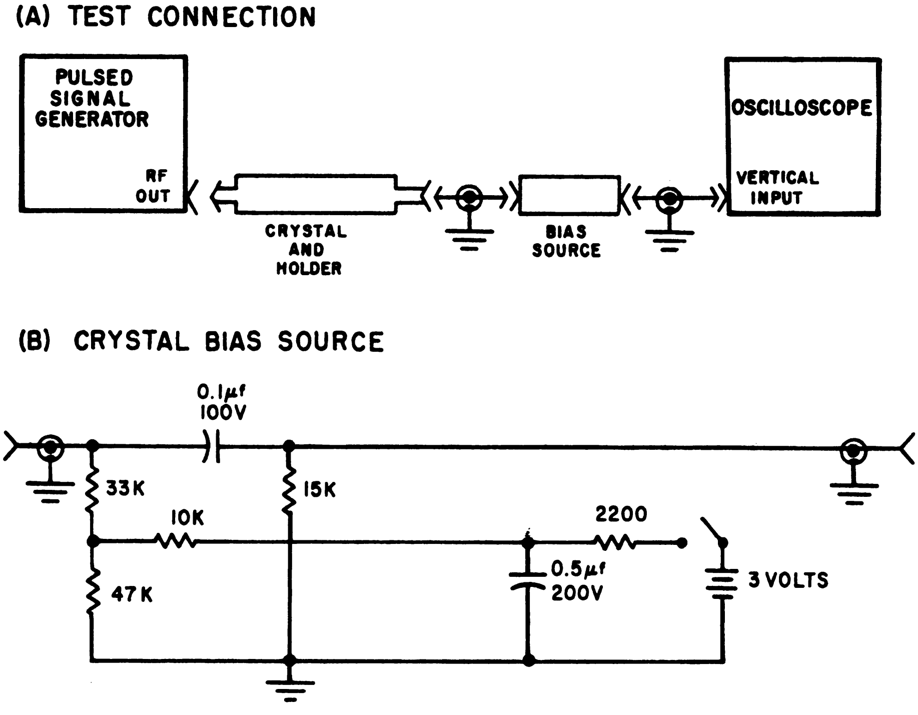
The signal generator used will depend on the frequency or frequencies where matching is desired. The crystal holder, bias source, and oscilloscope used will depend upon what is available and what crystals are being matched. Figure 19-14 (B) shows a bias source which may be locally made if a ready-built one is not available.

RADOMES

Most radar antennas must be protected by a radome. Much time, effort, and money have been expended in the development and production of radomes that will not degrade the performance of the radar. Radomes are precision devices built to close tolerances which must be maintained.

Most radomes that the AQ will come in contact with are of the type called sandwich-wall radomes. They are constructed of two or more thin skins and stabilized against buckling by lightweight core material. The skins are normally of fiberglass similar to that found in fiberglass boats. Many of the cores are made in the form of a honeycomb. Other cores are fluted or foam types.

The main problem of interest to the AQ is that of preventing physical damage to the radome during the performance of his job. The outer skin of the radome is sometimes sprayed with a rubber type substance to keep any contaminating fluids from causing damage to the walls. This coating must be protected from physical harm. The walls of the radome are very thin, but of sufficient strength to withstand



AQ.631

Figure 19-14.—Crystal matching procedure.

wind forces expected in flight. They are not built to withstand the stress which a sharp instrument may apply. Therefore, when handling radomes during maintenance, the technician must be especially careful not to slam it against any hard, sharp edges such as the edge of another aircraft control surface or against the corners of an auxiliary power unit.

The major maintenance consideration for radomes, other than handling carefully, is that of properly lubricating hinges in case the radome is of the hinged type. Keep the skin surfaces clean and free of oil or grease. If physical damage does occur, repair of the damage is dependent upon the extent of the damage and the area in which the damage occurs. Normally the AQ will not be required to make physical repairs since these are usually done by the squadron AM in the case of minor damage or by specialists at an intermediate or overhaul activity in case of extensive damage.

BORESIGHTING

Although boresighting is not as difficult a task as it once was, it is still a necessary maintenance function to maintain the weapon system accuracy. The accurate and effective delivery of aircraft firepower to a selected target is as dependent on accurate boresighting as on the proper operation of all other related equipment. Unless accuracy is maintained, the expense of the equipment involved is not justified.

The purpose of boresighting is to establish a specific relationship between the aircraft armament datum line, antenna RF and optical axes, optical sight unit, and launchers. If guns are aboard (other than the Mk 4 gun pod) they are also included in the boresight procedure. Normally, any adjustment required by the guns, launchers, and noncomputing sights is performed by the Ordnanceman. The AQ is responsible for the boresighting of the radar and computing gun sights.

The equipment necessary to carry out the boresight procedure varies from one installation to another. However, a boresight board or screen and a telescopic boresight kit with associated fixtures are normally required in all situations. In any case, the appropriate Maintenance Instructions Manual must be consulted for specifications pertaining to these items as well as test sets and other equipment needed.

The primary boresight reference to which the entire aircraft is alined is the zero-zero radar axis. This axis is the line in space along which the radar antenna will look when tracking a target with zero azimuth and zero elevation gimbal angles. The antenna is fitted with a boresight fixture to accept a telescopic sight for optical boresighting. This fixture can be used as a secondary reference after it is alined with the radar axis.

Satisfactory boresighting can be accomplished without radiating, provided the optical axis is in agreement with the RF axis of the radar antenna. This alinement will remain valid so long as no portion of the antenna structure is mechanically damaged. If there is reason to believe that the antenna has been mishandled, or if the feed horn or reflector appears to be deformed, a complete boresight should be conducted.

The first of three methods of boresight is called full boresight and provides for a complete RF and optical boresight, as a result of which the state of alinement of the radar axis and optical axis is determined. The Maintenance Instructions Manual should be consulted for the step-by-step procedure.

The second method is called radar silence boresight. It is the same as the first except that the telescope fixture is used as the only reference. This procedure can be used whenever it is impossible to radiate, or sufficient time does not exist for the full procedure.

The third method called fast boresight is only for use with director portion of the aircraft armament. This method can be used only when the aircraft has been boresighted previously, using the full procedure with a given antenna. This method can then be used to establish the electrical boresight of the director.

SACE

The complexity of the electronic systems today has necessitated the development of special avionics support equipment and the adoption of specific maintenance methods in order to maintain aircraft availability and effectiveness at a reasonable level.

Responsibility for quickly getting the aircraft "up" and available rests, first of all, at the organizational maintenance level. The aircraft is repaired at the organizational maintenance level by locating and replacing the defective ARA (Aircraft Replaceable Assembly).

The defective ARA is taken through supply to an intermediate level shop which has the responsibility for repairing and/or adjusting the ARA and returning it to supply as an RFI (ready for issue) item. If the defective ARA belongs to the group of equipments which do not lend themselves to automatic testing, it will be "substituted" into a test-bench harness and analyzed down to the module and/or component level by using more or less conventional test equipment. However, if the defective ARA belongs to one of the equipments or systems which can be checked with SACE (Semi-Automatic Checkout Equipment), it will be connected to the corresponding SACE adapter console and automatically fault isolated to the module level. When defective modules are located, they are immediately replaced and the ARA is ready for service.

The defective module moves on to the module repair area where it is fault isolated to the component level with a special test set. The special module test sets are not computer controlled and are, therefore, not part of SACE.

SACE Shop

The operation of an SACE shop is controlled by a programer comparator (shown in figure 19-15).

After the technician has connected the defective ARA to the appropriate SACE adapter test console (which, in turn, is connected to the programer comparator), he selects the correct programer comparator tape and inserts it into the programmer comparator. He then presses the start button and the testing begins. The tests, performed automatically and continuously by the test console, will stop only for special instructions or when a defective module is located.

Programer analyzer test consoles are provided to test the programer comparator. Figure 19-16 displays a programer analyzer test console.

VAST

VAST (Versatile Avionics Shop Test) will be the Navy's newest attempt to improve avionics maintenance and quicken turnaround time for avionics black boxes.

The VAST system, officially designated the AN/USM-247, will be installed in attack aircraft carriers (CVA) and at major shore

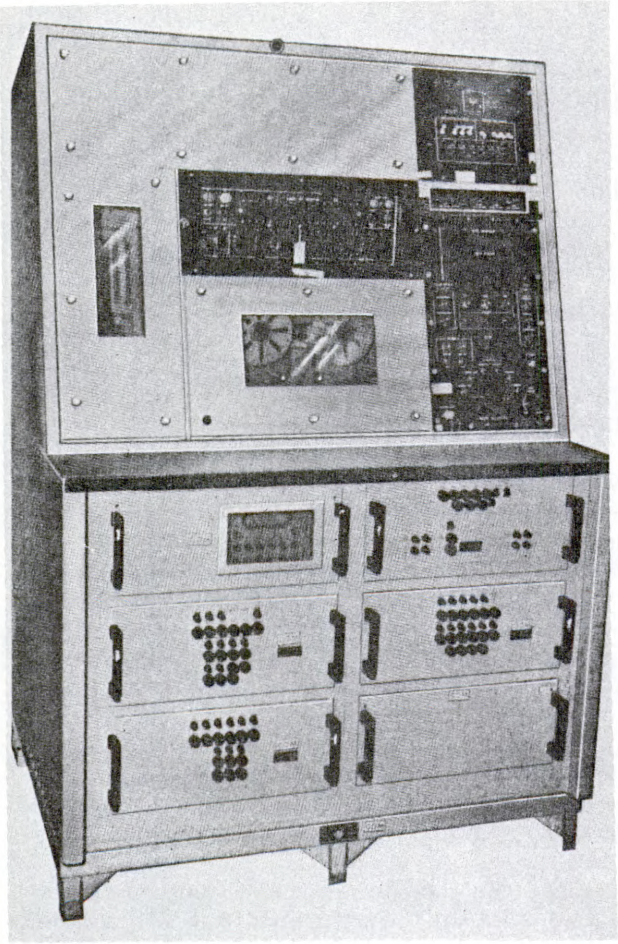


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Figure 19-15.—Programer comparator.

installations. VAST will be able to handle the testing and troubleshooting of 85 percent of the Navy's future avionic systems; the remainder, involving such items as inertial and hydraulic devices and radiating portions of radar and infrared systems, will still require special test facilities.

Where circumstances do not readily permit each WRA to be designed to be directly compatible with VAST, interface transformation units may be approved. In its simplest form, an interface transformation unit (ITU) may be merely a test cable which adapts the VAST connector to the assembly connector. More complex ITU's may require passive elements, active elements, and even programmable circuitry.

Avionic contractors must develop three types of test programs for each assembly which are

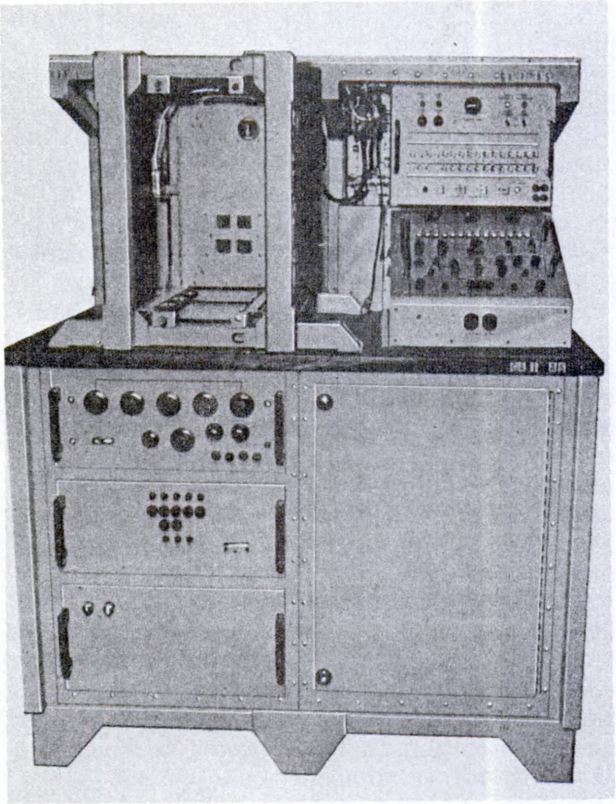

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Figure 19-16.—Programer analyzer console.

compatible with the AN/USM-247. These include the following:

1. Overall (end to end) test, to determine whether an assembly (WRA) is operating properly.
2. Module isolation test, to enable a fault to be traced to a replaceable module within the assembly.
3. Fault isolation test, to permit malfunction to be traced to lowest repairable level within a module.

The avionic contractor's first step in preparing the software for use by VAST will be to prepare a diagnostic flow chart. Next, diagrams, showing which of the available VAST building blocks are necessary for each test and the interface transformation unit requirements, must be prepared. The test diagrams must contain special instructions for mode of operation, floating ground points, shielding, test points, pin connections, and functional input/output requirements.

Finally, the avionic contractor must write an English language program (ELP) on special form. This lists such things as a functional description of each test, the stimulus level with acceptable tolerance, the allowable limits for satisfactory performance, and the next test to be performed, depending upon the results of the current test.

This contractor written ELP is then sent to a VAST programing center for conversion into the VTRAN language used by VAST.

VAST is designed for use with a general purpose digital computer. A single computer can serve as many as six individual test stations simultaneously on a time-share basis. Normally, only three test stations will share a single computer to enable each to operate as if it were the sole computer user.

VAST can operate in an automatic mode, in which the computer runs through a sequence of tests rapidly and stops only when it finds a malfunction; or, it can be operated in a manual mode in which the human operator selects the test to be conducted if he has a clue as to the nature of the fault.

VAST is also designed to perform self-test operations to check that all units are operational. If it detects a malfunction, VAST is able to isolate the malfunction to one of its basic building blocks and then trace the fault to the defective module.

APPENDIX I

FIRE CONTROL SYMBOLS

GUNNERY AND ROCKET:

Symbol	Definition
R	Present range.
R_f	Future range.
T	Indicated temperature.
t_f	Time of flight of projectile.
t_fL	Lost time of flight.
V_G	Groundspeed.
V_o	Average projectile velocity.
V_m	Muzzle velocity.
V_M	Missile velocity.
V_A	True airspeed.
Λ	Total lead angle.
Λ_A	Azimuth component of total lead angle.
Λ_E	Elevation component of total lead angle.
Λ_b	Ballistic lead angle.
Λ_{bA}	Azimuth component of ballistic lead angle.
Λ_{bE}	Elevation component of ballistic lead angle.
Λ_k	Kinematic lead angle.
Λ_{kA}	Azimuth component of kinematic lead angle.
Λ_{kE}	Elevation component of kinematic lead angle.
Λ_{bW}	Windage factor of ballistic lead.
Λ_{bWE}	Elevation component of the windage factor.
Λ_{bWA}	Azimuth component of the windage factor.
Λ_{bG}	Gravity factor of ballistic lead.
Λ_{bGE}	Elevation component of gravity factor.
Λ_{bGA}	Azimuth component of gravity factor.
P	Antenna position.
P_A	Antenna position in azimuth.
P_E	Antenna position in elevation.
ω	Angular velocity.
ω_A	Angular velocity in azimuth.
ω_E	Angular velocity in elevation.
P_S	Static air pressure.
λ_o	Gravity drop factor.
A_A	Angle of attack.
A_S	Angle of skid.
A_L	Launcher angle.
T_R	Rocket propellant temperature.
R_o	Preset future range.
D	Air density.
t	Time.
$1/t_f$	Inverse time of flight.
$\dot{R}$	Range rate.
E	Error term.
E_R	Range error term (range coil voltage).
E_E	Elevation error term (elevation coil voltage).
E_A	Azimuth error term (azimuth coil voltage).
E_H	Heading error.

GUNNERY AND ROCKET--Continued

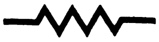
Symbol	Definition
E_{HE}	Heading error in elevation.
E_{HA}	Heading error in azimuth.
e_H	Steering error.
e_{HE}	Steering error in elevation.
e_{HA}	Steering error in azimuth.
a	Ballistic constant.
c	Ballistic constant.
T_d	Dome temperature.
N	Acceleration.
h	Ballistic constant (launching factor).
t_b	Rocket burn time.
V_b	Rocket burnt velocity.
V_o'	Velocity of projectile in vacuum.
ΔV_o	Decrease in velocity of projectile due to air drag.

BOMBING:

Symbol	Definition
y	Magnetic variation.
θ	True heading.
θ_m	Magnetic heading.
θ_R	Relative bearing.
η	True course.
η_R	Relative course.
μ	True bearing.
V_W	Wind velocity.
${}_RV_W$	Range wind.
${}_\mu V_W$	Cross wind.
R	Horizontal range.
H_T	Target altitude above sea level.
H_A	Aim point altitude above sea level.
H_O	Aircraft altitude above sea level.
H	Aircraft altitude above aim point.
V_H	Vertical velocity.
T	Ballistics.
S	Horizontal offset of target from aim point.
ψ	Angular position of S vector from true north.
P_V	Pitot air pressure.
P_S	Static air pressure.
T_S	Stagnation temperature.
r	Slant range.
ϕ	Elevation angle of line of sight.
V_R	Range rate.
V_μ	Azimuth rate.
R_o	Initial horizontal range.
t	Time.
k	Drift angle.
μ_o	Initial true bearing.
γ	Nonlinear V_G.
T'	Trail (in feet).
Δ	Change in a quantity when used as a prefix.
t_f	Time of fall.

APPENDIX II
SYMBOLS

RESISTORS:



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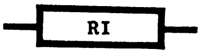

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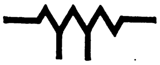

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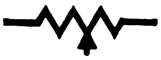
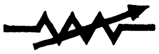
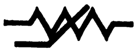


ADJUSTABLE
TAP

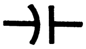


CONTINUOUSLY
VARIABLE



NONLINEAR

CAPACITORS:



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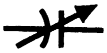
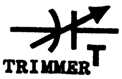


VARIABLE



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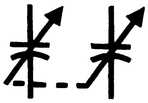

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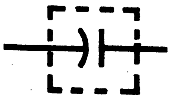

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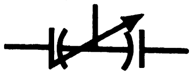
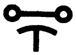
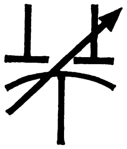


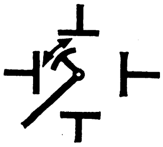
SPLIT-STATOR



FEED-THROUGH



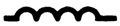
DIFFERENTIAL



PHASE SHIFT

(WHEN CAPACITOR ELECTRODE IDENTIFICATION IS NECESSARY, THE CURVED ELEMENT SHALL REPRESENT THE OUTSIDE ELECTRODE IN FIXED PAPER-DIELECTRIC AND CERAMIC-DIELECTRIC, THE NEGATIVE ELECTRODE IN ELECTROLYTIC CAPACITORS, THE MOVING ELEMENT IN VARIABLE AND ADJUSTABLE CAPACITORS, AND THE LOW POTENTIAL ELEMENT IN FEED-THROUGH CAPACITORS.)

INDUCTIVE COMPONENTS:



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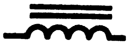
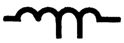


MAGNETIC
CORE



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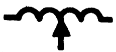

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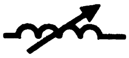
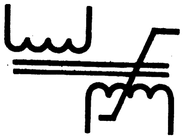
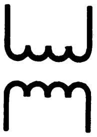


ADJUSTABLE OR
CONTINUOUSLY
ADJUSTABLE



SATURABLE
CORE REACTOR

TRANSFORMERS



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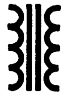
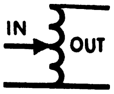
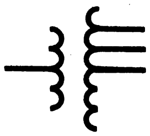


MAGNETIC CORE
TRANSFORMER

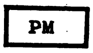


AUTOTRANSFORMER



WITH TAPS,
SINGLE-PHASE

PERMANENT MAGNET



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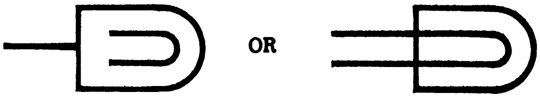

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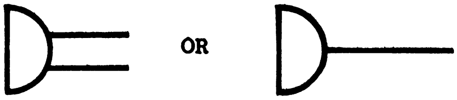

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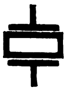
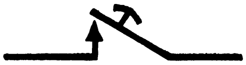


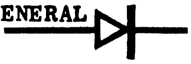
QUARTZ CRYSTAL;
PIEZOELECTRIC CRYSTAL
UNIT.

KEY

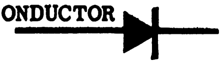


RECTIFIER

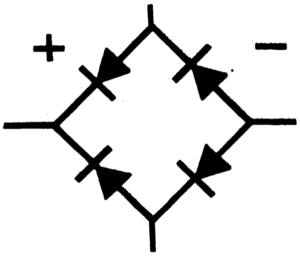
GENERAL



SEMICONDUCTOR

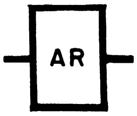


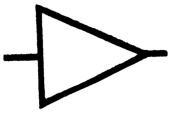
NORMAL CURRENT FLOW IS AGAINST THE ARROW



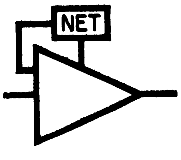
FULL WAVE BRIDGE TYPE

AMPLIFIER





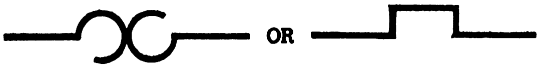
TRIANGLE POINTS
IN DIRECTION OF
TRANSMISSION
(SIGNAL FLOW)



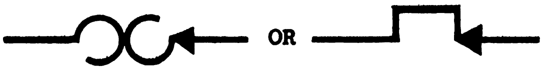
AMPLIFIER WITH
EXTERNAL
FEEDBACK PATH

BASIC SYMBOL INDICATES ANY METHOD OF AMPLIFICATIÓN EXCEPT THAT OPERATING ON THE PRINCIPLE OF ROTATING MACHINERY.

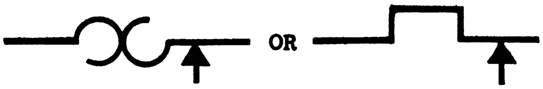
THERMAL ELEMENTS

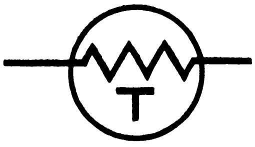


THERMAL RELAY WITH
NORMALLY CLOSED
CONTACT.

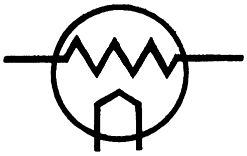


FLASHER; THERMAL CUTOUT

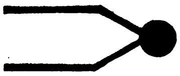




THERMISTOR

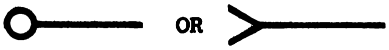


WITH INTEGRAL
HEATING ELEMENT

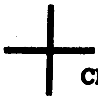


TEMPERATURE-MEASURING THERMOCOUPLE
(DISSIMILAR METAL DEVICE)

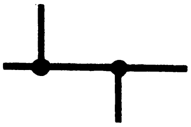
INPUTS (NONSTANDARD)



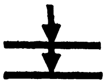
PATH, TRANSMISSION



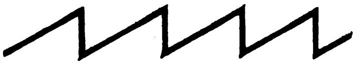
CROSSING NOT
CONNECTED



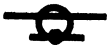
JUNCTION CONNECTED



TWISTED PAIR

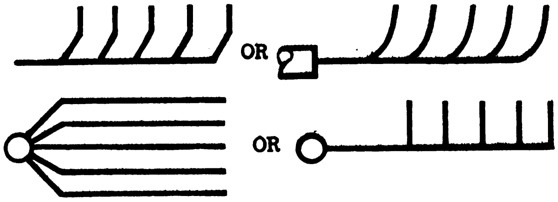


AIR OR SPACE PATH



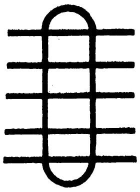
COAXIAL

GROUPING OF WIRES IN BUNDLES

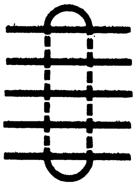


GROUPING OF WIRES IN CABLES

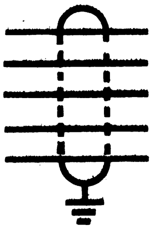
CABLES



FIVE-
CONDUCTOR
CABLE



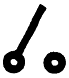
SHIELDED
FIVE-CONDUCTOR
CABLE



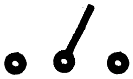
GROUNDED
SHIELD

NUMBER OF CONDUCTORS MAY BE ONE OR MORE AS NECESSARY

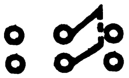
SWITCHES



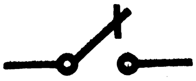
GENERAL
(SINGLE THROW)



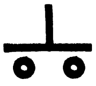
GENERAL
(DOUBLE THROW)



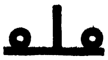
TWO POLE
DOUBLE THROW
SWITCH



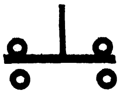
KNIFE SWITCH



PUSHBUTTON
(MAKE)

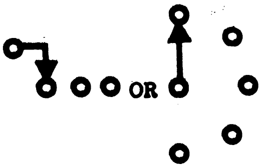


PUSHBUTTON
(BREAK)



PUSHBUTTON TWO CIRCUIT

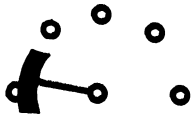
SELECTOR SWITCHES

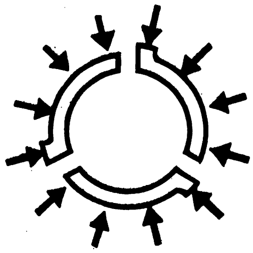


GENERAL

ANY NUMBER OF TRANSMISSION PATHS MAY BE SHOWN. ALSO BREAK BEFORE MAKE SWITCH.

MAKE BEFORE
BREAK

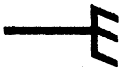




WAFER, TYPICAL 3-POLE, 3-CIRCUIT SWITCH. VIEWED FROM END OPPOSITE CONTROL KNOB. FOR MORE THAN ONE SECTION, #1 IS NEAREST CONTROL KNOB.

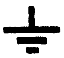
CIRCUIT RETURNS

CHASSIS CONNECTION



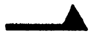
(THE CHASSIS OR FRAME IS NOT NECESSARILY AT GROUND POTENTIAL.)

GROUND

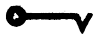


CONTACTS (ELECTRICAL)

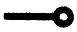
SWITCH



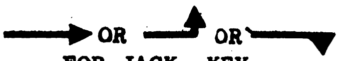
MOMENTARY
SWITCH



LOCKING



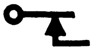
NONLOCKING



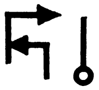
FOR JACK, KEY,
RELAY, ETC.

CONTACTS (ELECTRICAL) (Continued)

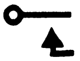
CONTACT ASSEMBLIES



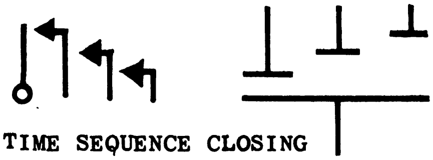
CLOSED CONTACT
(BREAK)



MAKE BEFORE
BREAK

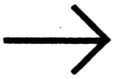


OPEN CONTACT
(MAKE)

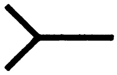


TIME SEQUENCE CLOSING

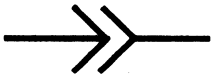
DISCONNECTING DEVICES



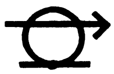
MALE
(PIN CONTACT)



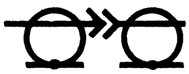
FEMALE
(SOCKET CONTACT)



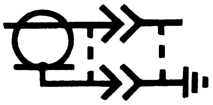
ENGAGED
(PIN-TO-SOCKET)



COAXIAL
(MALE)

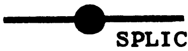


COAXIAL CONNECTORS
MATED

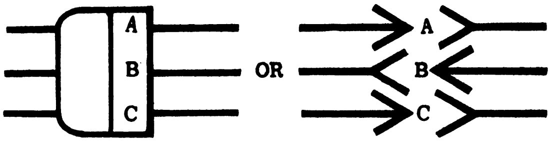


COAXIAL CONNECTED
TO SINGLE CONDUCTOR

THE CONNECTOR SYMBOL IS NOT AN ARROWHEAD. IT IS LARGER AND THE LINES ARE DRAWN AT A 90° ANGLE.



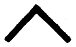
SPLICE



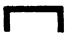
CONNECTOR ASSEMBLY (GENERAL)

ELECTRON TUBES

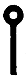
COMPONENT TUBE SYMBOLS



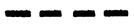
DIRECTLY-HEATED
(FILAMENTARY)
CATHODE



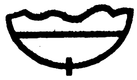
INDIRECTLY-HEATED
CATHODE



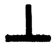
COLD
CATHODE



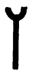
GRID



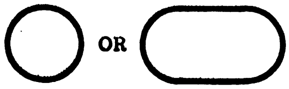
POOL CATHODE



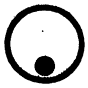
ANODE OR
PLATE



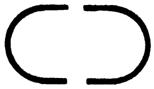
PHOTOCATHODE



ENVELOPE (SHELL)

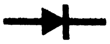


GAS FILLED
ENVELOPE

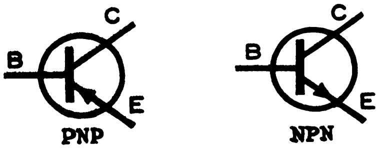


SPLIT ENVELOPE

SEMICONDUCTOR DEVICES

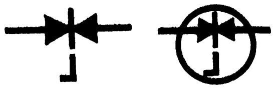


DIODE

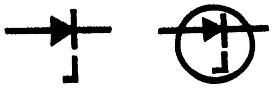


PNP NPN

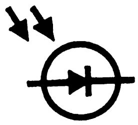
TRANSISTORS



BREAKDOWN DIODE,
BIDIRECTIONAL

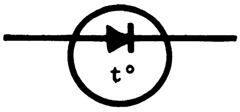


BREAKDOWN DIODE,
UNDIRECTIONAL
(ALSO BACKWARD DIODE)

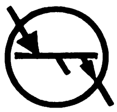


PHOTODIODE

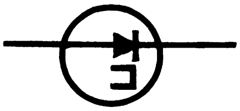
SEMICONDUCTOR DEVICES: (Continued)



TEMPERATURE
DEPENDENT DIODE

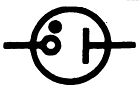


PNPN SWITCH

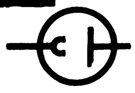


TUNNEL DIODE

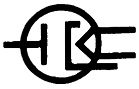
TYPICAL ELECTRON TUBES



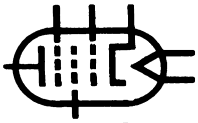
COLD CATHODE
GAS TUBE



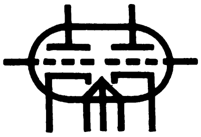
PHOTOTUBE SINGLE
UNIT, VACUUM



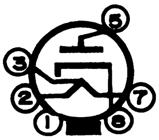
DIODE



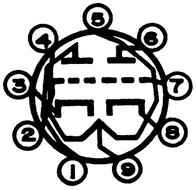
PENTODE



TWIN TRIODE
ILLUSTRATING
ELONGATED ENVELOPE

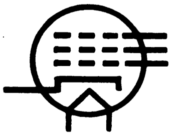


DIODE SHOWING BASE
CONNECTIONS

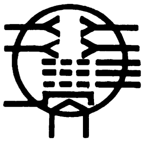


TWIN TRIODE WITH TAPPED HEATER

TYPICAL CATHODE RAY TUBES

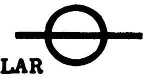


MAGNETIC DEFLECTION

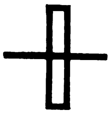


ELECTROSTATIC
DEFLECTION

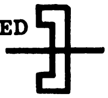
WAVEGUIDES



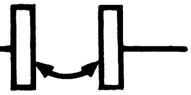
CIRCULAR



RECTANGULAR

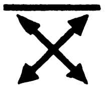


RIDGED

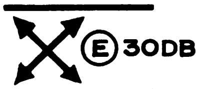


ROTARY
JOINT

DIRECTIONAL COUPLERS



GENERAL

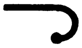


E PLANE APERTURE
COUPLING, 30 DB
TRANSMISSION LOSS

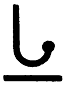
COUPLING METHODS

GENERALLY USED FOR COAXIAL
AND WAVEGUIDE TRANSMISSION.

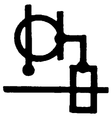
COUPLING BY APERTURE WITH AN OPENING OF LESS THAN FULL WAVEGUIDE SIZE. TYPE OF COUPLING WILL BE INDICATED WITHIN CIRCLE (E, H, OR HE).



COUPLING BY LOOP TO SPACE

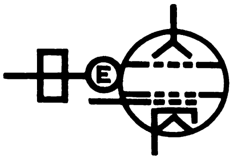


COUPLING BY LOOP TO GUIDED
TRANSMISSION PATH

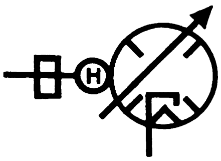


COUPLING BY PROBE FROM COAXIAL TO RECTANGULAR WAVEGUIDE WITH DIRECT-CURRENT GROUNDS CONNECTED

TYPICAL MAGNETRONS AND KLYSTRONS

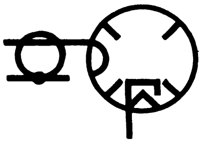


REFLEX KLYSTRON,
APERATURE COUPLED

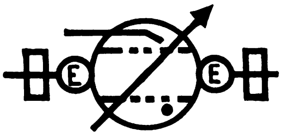


TUNABLE MAGNETRON,
APERTURE COUPLED

TYPICAL MAGNETRONS AND KLYSTRONS
(Continued)

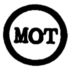


RESONANT TYPE WITH COAXIAL OUTPUT

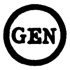


TRANSMIT-RECEIVE (TR) TUBE GAS FILLED, TUNABLE INTEGRAL CAVITY, APERTURE COUPLED, WITH STARTER

ROTATING MACHINES

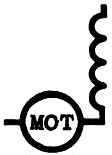


MOTOR

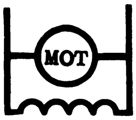


GENERATOR

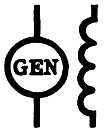
TYPES OF WINDINGS



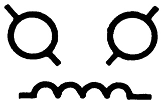
SERIES



SHUNT

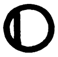


SEPARATELY EXCITED

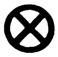


DYNAMOTOR

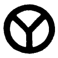
WINDING SYMBOLS



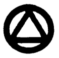
SINGLE-PHASE



TWO - PHASE



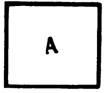
THREE-PHASE (WYE)



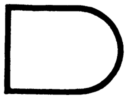
THREE-PHASE (DELTA)

LOGIC FUNCTIONS

AND FUNCTION

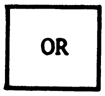


INPUT SIDE

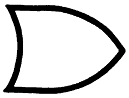


OUTPUT SIDE

INCLUSIVE OR FUNCTION

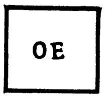


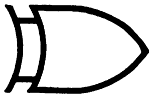
INPUT SIDE



OUTPUT SIDE

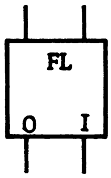
EXCLUSIVE OR FUNCTION



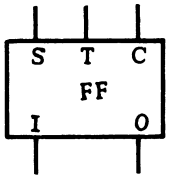


FLIP-FLOPS

LATCH



COMPLEMENTARY

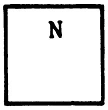


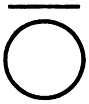
S-SET T-TRIGGER C-CLEAR

NEGATION

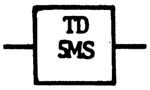
O

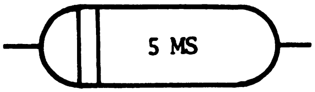
ELECTRIC INVERTER

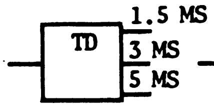


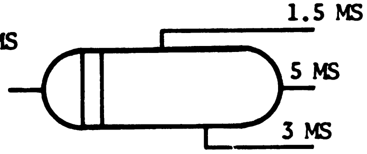


TIME DELAY



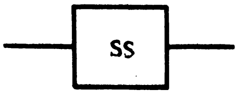




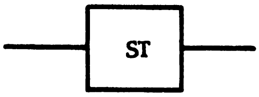


LOGIC FUNCTIONS (Continued)

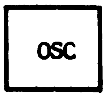
SINGLE SHOT

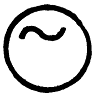


SCHMITT TRIGGER



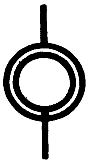
OSCILLATOR





SYNCHROS

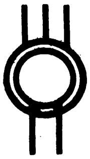
GENERAL



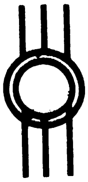
A LETTER COMBINATION FROM THE FOLLOWING LIST MAY BE PLACED ADJACENT TO THE SYMBOL TO INDICATE THE TYPE OF SYNCHRO:

TX - TORQUE TRANSMITTER
TDX - TORQUE DIFFERENTIAL TRANSMITTER
CX - CONTROL TRANSMITTER
CDX - CONTROL DIFFERENTIAL TRANSMITTER
TR - TORQUE RECEIVER
CT - CONTROL TRANSFORMER

SYNCHROS (Continued)

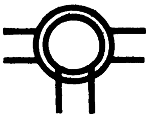


TRANSMITTER, RECEIVER, OR CONTROL TRANSFORMER

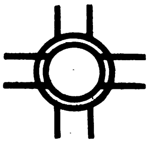


DIFFERENTIAL TRANSMITTER OR RECEIVER

RESOLVER (SYNCHRO)

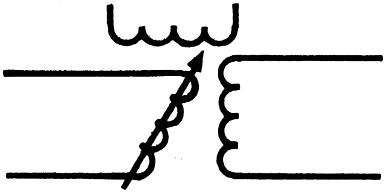


SINGLY-WOUND ROTOR

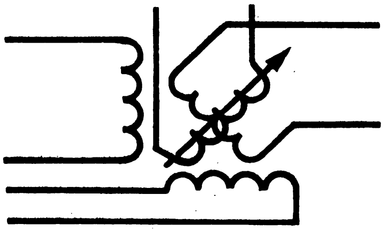


DOUBLY-WOUND ROTOR

RESOLVER

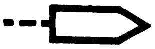


SINGLY-WOUND ROTOR

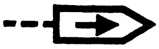


DOUBLY-WOUND ROTOR

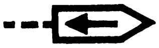
PICKUP HEADS



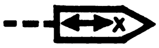
GENERAL



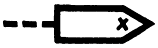
WRITING; RECORDING; HEAD, SOUND RECORDER



READING; PLAYBACK; HEAD, SOUND REPRODUCER

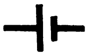


APPLICATION: WRITING, READING, AND ERASING

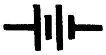


ERASING; ERASER, MAGNETIC

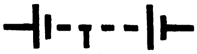
BATTERIES



ONE CELL



MULTICELL

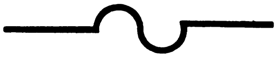


TAPPED MULTICELL

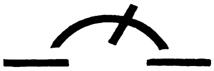
(LONG LINE IS ALWAYS POSITIVE)

CIRCUIT PROTECTORS

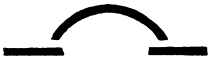
FUSE



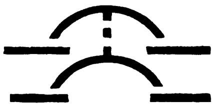
CIRCUIT BREAKERS



SWITCH

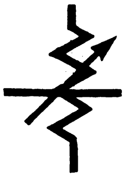


PUSH PULL OR PUSH



GANGED

ATTENUATORS



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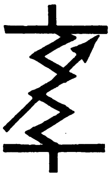
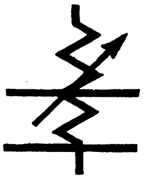


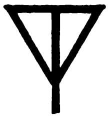
BALANCED



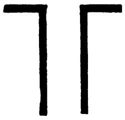
UNBALANCED

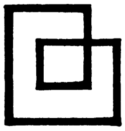
ANTENNAS

GENERAL

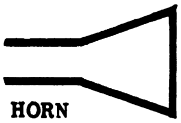


DIPOLE



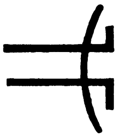


LOOP



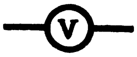
HORN

PARABOLIC



(NONSTANDARD)

METERS



A - AMMETER

CRO - OSCILLOSCOPE

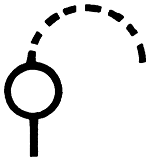
G - GALVANOMETER

MA - MILLIAMMETER

OHM - OHMMETER

V - VOLTMETER

HEADSET



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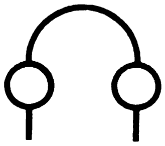


APPENDIX III

U.S. CUSTOMARY AND METRIC SYSTEM UNITS OF MEASUREMENTS

THESE PREFIXES MAY BE APPLIED TO ALL SI UNITS

Multiples and Submultiples	Prefixes	Symbols
1 000 000 000 000 = 10^{12}	tera (tĕr′ȧ)	T
1 000 000 000 = 10^{9}	giga (jĭ′gȧ)	G
1 000 000 = 10^{6}	mega (mĕg′ȧ)	M*
1 000 = 10^{3}	kilo (kĭl′ō̍)	k*
100 = 10^{3}	hecto (hĕk′tō̍)	h
10 = 10	deka (dĕk′ȧ)	da
0.1 = 10^{-1}	deci (dĕs′ĭ)	d
0.01 = 10^{-2}	centi (sĕn′tĭ)	c*
0.001 = 10^{-2}	milli (mĭl′ĭ)	m*
0.000 001 = 10^{-6}	micro (mī′krō̍)	μ*
0.000 000 001 = 10^{-6}	nano (năn′ō̍)	n
0.000 000 000 001 = 10^{-12}	pico (pē′kō̍)	p
0.000 000 000 000 001 = 10^{-15}	femto (fĕm′tō̍)	f
0.000 000 000 000 000 001 = 10^{-18}	atto (ăt′tō̍)	a

*Most commonly used

COMMON EQUIVALENTS AND CONVERSIONS

Approximate Common Equivalents

1 inch	= 25 millimeters
1 foot	= 0.3 meter
1 yard	= 0.9 meter
1 mile	= 1.6 kilometers
1 square inch	= 6.5 square centimeters
1 square foot	= 0.09 square meter
1 square yard	= 0.8 square meter
1 acre	= 0.4 hectare †
1 cubic inch	= 16 cubic centimeters
1 cubic foot	= 0.03 cubic meter
1 cubic yard	= 0.8 cubic meter
1 quart (lq.)	= 1 liter †
1 gallon	= 0.004 cubic meter
1 ounce (avdp)	= 28 grams
1 pound (avdp)	= 0.45 kilogram
1 horsepower	= 0.75 kilowatt
1 millimeter	= 0.04 inch
1 meter	= 3.3 feet
1 meter	= 1.1 yards
1 kilometer	= 0.6 mile
1 square centimeter	= 0.16 square inch
1 square meter	= 11 square feet
1 square meter	= 1.2 square yards
1 hectare †	= 2.5 acres
1 cubic centimeter	= 0.06 cubic inch
1 cubic meter	= 35 cubic feet
1 cubic meter	= 1.3 cubic yards
1 liter †	= 1 quart (lq.)
1 cubic meter	= 250 gallons
1 gram	= 0.035 ounces (avdp)
1 kilogram	= 2.2 pounds (avdp)
1 kilowatt	= 1.3 horsepower

† common term not used in SI

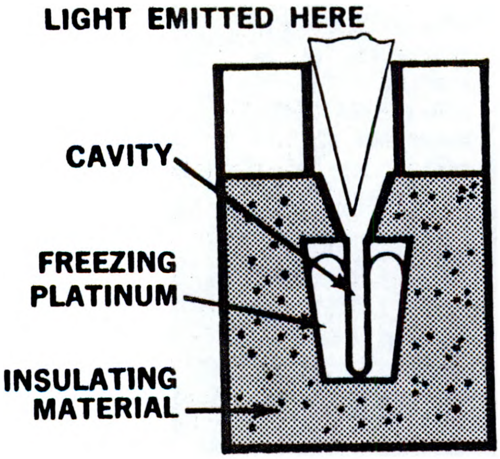
Conversions Accurate to Parts Per Million

inches x 25.4*	= millimeters
feet x 0.3048*	= meters
yards x 0.9144*	= meters
miles x 1.609 34	= kilometers
square inches x 6.4516*	= square centimeters
square feet x 0.092 903 0	= square meters
square yards x 0.836 127	= square meters
acres x 0.404 686	= hectares
cubic inches x 16.3871	= cubic centimeters
cubic feet x 0.028 316 8	= cubic meters
cubic yards x 0.764 555	= cubic meters
quarts (lq.) x 0.946 353	= liters
gallons x 0.003 785 41	= cubic meters
ounces (avdp) x 28.349 5	= grams
pounds (avdp) x 0.453 592	= kilograms
horsepower x 0.745 700	= kilowatts
millimeters x 0.039 370 1	= inches
meters x 3.280 84	= feet
meters x 1.093 61	= yards
kilometers x 0.621 371	= miles
square centimeters x 0.155 000	= square inches
square meters x 10.7639	= square feet
square meters x 1.195 99	= square yards
hectares x 2.471 05	= acres
cubic centimeters x 0.061 023 7	= cubic inches
cubic meters x 35.3147	= cubic feet
cubic meters x 1.307 95	= cubic yards
liters x 1.056 69	= quarts (lq.)
cubic meters x 264.172	= gallons
grams x 035 274 0	= ounces (avdp)
kilograms x 2.204 62	= pounds (avdp)
kilowatts x 1.341 02	= horsepower

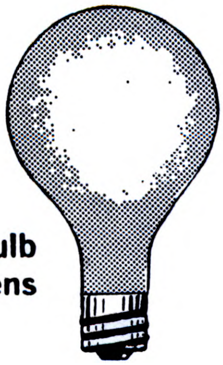
*exact

Luminous Intensity CANDELA–cd

The candela is defined as the luminous intensity of 1/600 000 of a square meter of a radiating cavity at the temperature of freezing platinum (2042 K).



The SI unit of light flux is the lumen (lm). A source having an intensity of 1 candela in all directions radiates a light flux of 4π lumens.



A 100-watt light bulb emits about 1700 lumens

APPENDIX IV
SET INDICATOR LETTERS

Installation	Type of equipment	Purpose
A—Airborne (installed and operated in aircraft).	A—Invisible light, heat radiation.	A—Auxiliary assemblies (not complete operating sets).
B—Underwater mobile, submarine	C—Carrier.	B—Bombing.
C—Air transportable.	D—Radiac.	C—Communication (receiving and transmitting).
D—Pilotless carrier.	E—Nupac (nuclear protection and control).	D—Direction finder.
F—Fixed.	F—Photographic.	E—Ejection and/or release.
G—Ground, general ground use (includes two or more ground installations).	G—Telegraph or teletype.	G—Fire control or searchlight directing.
K—Amphibious.	I—Interphone and public address.	H—Recording and/or reproducing (graphic, meteorological, and sound).
M—Ground, mobile (installed as operating unit in a vehicle which has no functions other than transporting the equipment).	J—Electromechanical (not otherwise covered). K—Telemetering. L—Countermeasure.	M—Maintenance and test assemsemblies (including tools).
P—Pack or portable (animal or man).	M—Meteorological. N—Sound in air. P—Radar.	N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach and landing).
S—Water surface craft.	Q—Sonar and underwater sound.	Q—Special purpose or combination of purposes.
T—Ground, transportable.	R—Radio.	
U—General utility (includes two or more general installation classes, airborne, shipboard, and ground).	S—Special types (magnetics, etc.) or combination of types. T—Telephone (wire).	R—Receiving, passive detecting. S—Detecting and/or range and bearing.
V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, such as tanks).	V—Visual and visible light. W—Armament (peculiar to armament, not otherwise covered). X—Facsimile or television.	T—Transmitting. W—Control X—Identification and recognition.
W—Water; surface and undersurface.		

APPENDIX V
UNIT INDICATOR LETTERS

Comp. ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
AB	Supports, antenna	Antenna mounts, mast bases, mast sections, towers, etc.
AM	Amplifiers	Power, audio, interphone, radiofrequency, video, etc.
AS	Antenna assemblies	Complex: Arrays, parabolic types, masthead, etc.
AT	Antenna	Simple: whip or telescopic, loop, dipole, reflector, also transducer, etc.
BA	Battery, primary type	B batteries, battery packs, etc.
BB	Battery, secondary type	Storage batteries, battery packs, etc.
BZ	Signal devices audible	Buzzers, gongs, horns, etc.
C	Control articles	Control box, remote tuning control, etc.
CA	Commutator assemblies, sonar	Peculiar to sonar equipment.
CB	Capacitor bank	Used as power supply.
CG	Cables and transmission lines	RF cables, waveguides, etc., with terminals.
CK	Crystal kits	A kit of crystals with holders.
CM	Comparators	Analyzes or compares two or more input signals.
CN	Compensators	Electrical and/or mechanical compensating regulating or attenuating apparatus.
CP	Computers	A mechanical and/or electronic mathematical calculating device.
CR	Crystals	Crystal in crystal holder.
CU	Coupling devices	Impedance coupling devices, directional couplers, etc.
CV	Converters (electronic)	Electronic apparatus for changing the phase or frequency, or from one medium to another.
CW	Covers	Cover, bag, roll, cap, radome nacelle, etc.
CX	Cords	Cord with terminals, also composite cables of RF and non-RF conductors.
CY	Cases	Rigid and semirigid structure for housing or carrying equipment.
DA	Antenna dummy	RF test loads.
DT	Detecting heads	Magnetic pickup device, search coil, hydrophone, etc.
DY	Dynamotors	Dynamotor power supply.
E	Hoist assembly	Sonar hoist assembly, etc.
F	Filters	Bandpass, noise, telephone, wave traps, etc.
FR	Frequency measuring devices	Frequency meters, echo boxes, etc.

Comp. Ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
G	Generators	Electrical power generators without prime movers. (See PU and PD).
GO	Goniometers	Goniometers of all types.
H	Head, hand and chest sets	Includes earphones.
HC	Crystal holder	Crystal holder less crystal.
HD	Air-conditioning appartus	Heating, cooling, dehumidifying, pressure, and vacuum devices.
ID	Indicating devices	Calibrated dials and meters, indicating lights, etc. (see IP.)
IL	Insulators	Strain, standoff, feed-through, etc.
IM	Intensity measuring devices	Includes SWR gear, field intensity and noise meters, etc.
IP	Indicators, cathode-ray tube	Azimuth elevation, PPI panoramic, etc.
J	Junction devices	Junction, jack, and terminal boxes: connectors, panels, etc.
KY	Keying devices	Mechanical, electrical, and electronic keys, coders, and interrupters.
LS	Loudspeakers	Separately housed loudspeakers.
M	Microphones	Radio telephone, throat, hand, etc.
MD	Modulators	Device for varying amplitude, frequency, or both.
ME	Meters, portable	Multimeters, volt-ohm-milliammeters, vacuum tube voltmeters, power meters, etc.
MK	Maintenance kits or equipment	Radio telephone general utility, etc.
ML	Meteorological devices	Barometer, hygrometer, and thermometer scales.
MT	Mountings	Mountings, racks, frames, stands, etc.
MX	Miscellaneous	Equipment not otherwise classified. Do not use if better indicator is available.
O	Oscillators	Master frequency, blocking multivibrators, etc. (For test oscillators, see SG.)
OA	Operating assemblies	Operating units associated together not otherwise covered.
OS	Oscilloscope test	Test oscilloscopes for general test purposes.
PD	Prime drivers	Gasoline engines, electric motors, diesel motors, etc.
PH	Photographic articles	Camera, projector, sensitometer, etc.

Comp. Ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
PP	Power supplies	Nonrotating machine type such as vibrator pack, rectifier, thermoelectric, etc.
PT	Plotting equipments	Except meteorological boards, maps, plotting table, etc.
PU	Power equipments	Rotating power equipment except dynamotors, moter-generator, etc.
R	Radio and radar receivers	Radio or radar receiver, composite receiver indicator, etc.
RD	Recorders and Reproducers.	Tape and facsimile, disk magnetic, etc.
RE	Relay assemblies	Electrical, electronic, etc.
RF	Radiofrequency component	Composite, component of RF circuits. Do not use if better indicator is available.
RG	Cable and transmission line, bulk, RF	RF cable, waveguide, etc., without terminal.
RL	Reel assemblies	Antenna, field wire, etc.
RR	Reflectors	Target confusion, etc. Except antenna reflectors. (see AT.)
RT	Receiver and transmitter	Radio and radar transceivers, composite transmitter and receiver, etc.
SA	Switching devices	Manual, impact, motor driven, pressure operated.
SB	Switchboards	Telephone, fire control, power, panel, etc.
SG	Generators, signal	Includes test oscillators and noise generators. (See O.)
SM	Simulators	Flight, aircraft, target, signal, etc.
SN	Synchronizers	Equipment to coordinate two or more functions.
T	Radio and radar transmitters	Communications, range, marker beacon, interrogator, composite transmitter-modulator, sonar drivers, etc.
TA	Telephone apparatus	Miscellaneous telephone equipment.
TD	Timing devices	Mechanical and electronic timing devices, range device, etc.
TF	Transformers	Transformers when used as separate items.
TG	Positioning devices	Tilt and/or train assemblies.
TK	Toolkits or equipments	Miscellaneous tool assemblies
TL	Tools	All types except line construction.
TN	Tuning units	Receiver transmitter, antenna, etc.
TS	Test equipment	Test and measuring equipment including multipurpose testing devices not otherwise included.

Comp. Ind.	Family name	Definition of example (not to be construed as limiting the application of the component indicator)
TT	Teletypewriter and facsimile apparatus	Miscellaneous tape, teletype, and facsimile.
TV	Tester, tube	Vacuum tube tester.
U	Connectors, audio and power	Union, plugs, sockets, adapters, etc.
UG	Connectors, RF	Union, plugs, sockets, choke couplings, adapters, elbows, flanges, etc.
V	Vehicles	Carts, dollies, trucks, trailers, etc.
VS	Signaling equipment visual	Flag sets, serial panels, signal lamp equipment.
WD	Cables, two conductor	Includes non-RF wire, cable, and cordage in bulk.
WF	Cables, four conductor	Includes non-RF wire, cable, and cordage in bulk.
WM	Cables, multiple conductor	Includes non-RF wire, cable, and cordage in bulk.
WS	Cables, single conductor	Includes non-RF wire, cable, and cordage in bulk.
WT	Cables, three conductor	Includes non-RF wire, cable, and cordage in bulk.
ZM	Impedance measuring devices	Used for measuring Q, C, L, R, or PF, etc.

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